1831 1959

THE ADVANCEMENT OF SCIENCE

VOL. XV NO. 60 MARCH 1959

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THE VISIT OF HIS ROYAL HIGHNESS THE DUKE OF EDINBURGH, K.G., TO INDIA AND PAKISTAN, 1959

His Royal Highness The Duke of Edinburgh, K.G., has honoured the Association by representing it at the Annual Meetings of the Indian Science Congress in New Delhi in January, 1959, and of the Pakistan Association for the Advancement of Science in Karachi in February, 1959. He was accompanied by Sir Alexander Fleck, K.B.E., F.R.S., immediate Past President of the Association.

The texts of the Addresses delivered by the Duke of Edinburgh in New Delhi on January 22, 1959, and in Karachi on February 7, 1959, are printed in full below.

THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE[1]

By H.R.H. The Duke of Edinburgh, K.G.

Eighteen years ago I spent two days in Bombay, it was during the War, and the Monsoon had just started. Not a very promising start but it was enough to set me dreaming of the day when I might see a bit more of India.

So many members of my family have been closely associated with India and so many Englishmen have such a very special place in their affections for India that I hardly feel a stranger here. Indeed, it would be very odd to feel strange after hearing so much about this country and her people from that great friend of India, my uncle Lord Mountbatten. I am very much looking forward to the rather hectic and entirely inadequate fortnight I am to spend in this country.

Mr. Chancellor, having said how happy I am to be here today, may I also say how grateful I am to you and to your University for conferring this Honorary Degree upon me. It may be surrounded by a certain amount of ceremony but that does not hide the fact that it is a most friendly gesture of welcome.

I regret to say that my only Degrees are Honorary ones, a fact which will become only too apparent during my Address about the British Association. However, before I go into that I have two very pleasant duties to perform.

First, I would like to read out a message from the Head of our Commonwealth, The Queen:

> As Head of the Commonwealth, I am delighted to take the opportunity of my husband's visit to Delhi to send my warm greetings to all members of the Indian Science Congress and my best wishes for the success of their deliberations.
>
> Elizabeth R.

My next job is to offer all the members of the Indian Science Congress the warmest fraternal greetings from all the members of the British Association for the Advancement of Science. I need hardly add how grateful I am to both organisations for making this visit possible.

Now, about the British Association. I have had a most interesting time finding out about this body and its origins. During this process my attention was drawn to a passage in a book written in the year 1602 by Sir Francis Bacon. The book is called *The Advancement of Learning* and the second half, which he left unfinished, is called *The New Atlantis*. In this, Bacon describes a visit to a lost continent which

[1] Address delivered to the Indian Science Congress on January 22, 1959.

must have been his idea of Utopia. In one passage the Father of Solomon's House, who is obviously the Atlantis Director of the Department of Scientific and Industrial Research, describes his whole organisation of science and learning and the facilities for research and experiment. One group, for instance, is charged to 'look into the experiments of their fellows and cast about how to draw out of them things of use and practice for man's life and knowledge'. He concludes the passage with these words: 'Lastly, we have circuits or visits of divers principal cities of the kingdom: where, as it cometh to pass, we do publish new profitable inventions as we think good'.

This obviously looks like the origin of the Association but, unfortunately, Bacon was only discovered to be a prophet after the event. It turns out that the Association was copied from a German Society formed in 1822. It came about like this. The period after the Napoleonic Wars was one of protracted reconstruction and reformation in the British Isles but in this process science and scientists were given scant attention. This situation soon provoked the leading scientists of the time to complain of the decline of science and the neglect of scientists. For instance, Sir David Brewster wrote: 'The abolition of the Board of Longitude, the only scientific board in the Kingdom, at last proclaimed the mortifying intelligence that England had renounced by Act of Parliament her patronage, even of the sciences most intimately connected with her Naval greatness'.

Slowly and by degrees a body of opinion grew up which felt that something ought to be done about this serious situation. The difficulty, as usual, was to decide what to do. It so happened that just about this time a German Society under the name of the 'Deutsche Naturforscher Versammlung' was beginning to make a considerable impression in scientific circles. Its first meeting in Leipzig in 1822 attracted about thirty scientists but by 1828 it was able to hold its meeting in Berlin with Government blessing. Incidentally, it was accompanied by a round of social junketing, a feature which was also copied and which has survived to the present day. Several of the early meetings had been attended by British scientists and their reports raised great hopes that this would prove to be a powerful method of putting science on the map.

It is not surprising to find Sir David Brewster hard at work on this new idea and early in 1831 he had persuaded the Yorkshire Philosophical Society to organise the first meeting of the British Association in York in the summer of that year. In his letter to the Secretary of the Yorkshire Society occurs this paragraph: 'The principal objects of the Society would be to make the cultivators of science acquainted with each other; to stimulate one another to new exertions; to bring the objects of science more before the public eye and to take measures for advancing its interest and for accelerating its progress'. A statement which it would be hard to improve even today.

The first meeting in York in 1831 went off extraordinarily well and since that time the annual meetings have been uninterrupted except during the two Great Wars.

This all makes the whole thing sound quite easy and straightforward: in fact, the new Association had to battle in the early years against very considerable odds. For instance, just before setting off for the first meeting, the President of the Geological Society received a letter from the Editor of the *Quarterly Review* in which he says: 'I presume you are going to the colt-show at York. Don't make a fool of yourself among these twaddlers. . . .'

A few years later Charles Dickens enjoyed himself at the expense of the British Association in a series of articles called 'The Mudfog Papers', in which he deals with the meetings of 'The Mudfog Association for the Advancement of Everything'. Splendid characters like Professors Snore, Doze and Wheezy, Messrs. Muddlebranes and Drawley, Rummun and Pumpkinskull address and argue in sections

devoted to Umbugology and Ditchwateristics. The meetings were held at a public house called 'The Original Pig' and the paper read to the Umbugology section dealt with the question of a one-eyed bay pony which invariably winked its eye and whisked its tail at the same moment. The final comment is provided by Professor Woodensconse at the culminating banquet: 'This is what we meet for, this is what inspires us, this is what keeps us together and beckons us onward, this is the spread of science, and a glorious spread it is'.

On top of this the British Association had to struggle against the Olympian hostility and derision of *The Times*. On August 26, 1840, the leading article in that newspaper remarked: 'In a week or two hence the British Association, which bears exactly the same relationship to the regular forces of philosophy as a militia regiment does to the troops of the line, will go into quarters, according to its annual practice, for a few days' pastime and parade. . . .' and it goes on to mention the decision 'to pitch their tents this year in the large city of Glasgow, which, while sufficiently distant from their last encampment to encourage a hope that the scandal of former fooleries may not have reached the West of Scotland, is a peculiarly favourable locality for securing a staring crowd'. The article ends up in a proper frenzy of indignation with 'When shall this monstrous bubble burst?' It seems almost a pity to have to report that *The Times* changed its mind and is now one of the greatest supporters of the British Association.

It is difficult to pin down the secret of the Association's success but I would hazard that its straightforward objectives and its basically simple organisation must share much of the credit. However, in the end every Society stands or falls by the people who devote themselves to it. In this respect the Association has been most fortunate. Many brilliant and famous men of science have thought it worth while to lend their time and energy to foster the progress of the Association. The list of Presidents alone reads rather like a telephone directory in the Hall of Fame; that is, of course, if you leave out a few names like mine, which are only conspicuous because they are so incongruous.

The Association is now 128 years old and it might well be excused for being perhaps a bit old-fashioned, but it is in fact far from being so, it has developed and adapted itself to changing circumstances and needs so successfully that today its reputation is higher and its activity greater than ever before. What is more, it can look back and say that it is still achieving the things it set out to do.

I do not propose to trace the development of the Association or to describe the many arguments that took place about, for instance, the formation of new sections, whether to move the annual meetings from place to place, whether women should be allowed to attend and the many other domestic discussions which have contributed to the Association's growth and domestic health.

On the other hand, there have been several meetings of the Association at which matters of fundamental interest to all people were thrashed out or explained in the full glare of publicity.

The first of these classic occasions occurred at the second meeting at York in 1844 when for the first time science and the Church collided head-on although the Church itself was divided before the collision. The cause of the trouble was the advancement of the evolutionary theory of the formation of the earth which conflicted with the literal interpretation of the Scriptures which allowed the process only a period of days.

An extraordinary sidelight on this business is that when the British Association was launched, only thirteen years previously, twelve places on the scientific sub-Committees out of forty-one were filled by clergymen.

The second occasion was a battle between science and orthodoxy as a whole. In 1859 Charles Darwin's *Origin of Species* appeared; by the time of the 1860 Meeting the two sides had taken up their positions and appointed their champions.

On Darwin's side, Hooker and Huxley; on the other side, Owen and Bishop Wilberforce. Huxley realised the high state in which feelings were running in the country and pleaded that 'a general audience, in which sentiment would unduly interfere with intellect, was not the public before which such a discussion should be carried on'.

However, battle was joined and the most famous engagement between Wilberforce and Huxley reached its climax when the Bishop, rather unwisely, refused, for himself, to regard monkeys as his ancestors and turned to Huxley to ask whether it was through his grandfather or his grandmother that he claimed descent from a 'venerable ape'. Huxley, with, one feels, great restraint, replied:

> If I am asked whether I would choose to be descended from the poor animal of low intelligence and stooping gait, who grins and chatters as we pass, or from a man, endowed with great ability and a splendid position, who should use these gifts to discredit and crush humble seekers after truth, I hesitate what answer to make.

That did not quite end the argument, which went on for several years, but since then the forces of orthodoxy have been reluctant to face an all-out clash, although pale shadows of the Darwinian engagement were fought in 1903 on Atomic Disintegration, in 1907 on Atomic Structure and in 1912 on the Origin of Life.

Though in our own day scientific pronouncements are unlikely to cause this sort of controversy, the Addresses of Presidents of the Association frequently cause considerable discussion. In 1952 Professor Hill spoke out about some of the moral and economic problems of the application of science and, again in 1957 Professor Blackett caused quite a stir when he spoke about the effect of science and technology on the material way of life of mankind and the dangers resulting from the widening gap between the wealth of the rich and the poor countries of the world. Afterwards he wrote:

> I expected controversy and got it. . . . Critics evidently thought I should have talked about my particular interests, such as 'the Elementary Particles of Nature' or 'Cosmic Rays' . . . But what I think the British Association audiences at the Inaugural Meeting prefer, and I think rightly so, is a discussion of some major problem of the application of science to human life. This may be on the mental plane . . . then one is led at once into the controversial fields of philosophy, religion and morals. Or one can deal with the effect of science on the material way of life of mankind . . . then one is led right into the very heart of economics and political controversy.

There is no doubt that these discussions have contributed in a large measure to the advancement of science and scientific thinking but this is not the only contribution which the Association has made. There have been many occasions when announcements of immense scientific importance have been made at the annual meetings. In 1873 Clerk Maxwell read his paper on Molecular Physics; in 1879 Crookes described what we now call a cathode ray tube; in 1894 Rayleigh and Ramsay announced the discovery of Argon and in 1899 J. J. Thompson read his paper on the existence of masses smaller than atoms. This was followed in 1907 by a discussion opened by Rutherford on the constitution of the atom. I suppose somebody realised what those early researches were going to lead to.

In more recent years the steps in scientific advancement have been more specialised and less easily understood by the general public, and although the general importance of papers can only be judged by scientists, it is even more necessary that they should be clearly and carefully written for the benefit of the layman. For instance, in 1933 Cockcroft and Walton presented a paper on 'The Transmutation of Elements by High Velocity Protons', and at the same meeting Sir Arthur Eddington opened a discussion on 'The Theory of the Expanding Universe'. More recently, at a section meeting in 1950, Blackett described 'The

Existence of Giant Meson in Atoms' and in 1955 Sir Alexander Todd spoke about the investigation into the structure of Nucleic acid. . . .

It is quite easy to talk about pure science as opposed to applied science or technology but in fact it is not a simple matter to establish the exact dividing line. In any event, if one of the intentions of the British Association is to present science to the public, the applied scientist and technologist can obviously present the most convincing case. It is not, therefore, surprising to find that in 1856 Bessemer produced a paper on his converter for steel, which revolutionised that industry, or that in 1876 Kelvin demonstrated the first telephone and in 1894 Lodge showed off 'wireless'—both for the first time in the United Kingdom. I could go on giving examples of this sort but my purpose is only to illustrate the general way in which the Association performs its function.

So far I have only mentioned the Association's direct contribution to the advancement of science through the addresses and discussions of famous scientists. No less valuable in the long run have been the indirect attempts to encourage science. For many years sums of money, some quite small and some over £1,000, have been allocated to specific research projects. In a hundred years 700 projects were supported involving more than £100,000. This may not seem very impressive but the money was allocated by scientists for scientists at a time when a little went a long way. In all cases the grant meant a project started or a project completed so that its effect was out of all proportion to the sum involved.

It would take me far too long and it would try your patience most dreadfully if I attempted a comprehensive survey of the influence which the Association has had upon the general progress of science. However, I have picked out one or two examples. The Association ran the Observatory at Kew for many years and in 1864 the report shows that Kew was the first public institution to take up the subject of sunspots. The National Physical Laboratory owes its existence to a suggestion made by Sir Oliver Lodge at the 1891 Meeting. As early as 1839 the Association started a Catalogue of the Stars. In 1852 the Association, together with the Royal Society and others, was actively involved in a series of balloon ascents—the best reached 22,940 feet—and organised the meteorological observations which were the main purpose of the ascents. And so the list goes on, Ordnance Survey of Scotland, Magnetic Survey of British India, the Department of Industrial and Scientific Research, Science in Schools, Marine Biological Research in India and a thousand other subjects were discussed, encouraged and supported by the Association.

It is probably no longer quite so important to impress upon Governments the value of science and scientific research. Most of them seem to realise that now, even if they are a bit reluctant to foot the bill. However, now that science depends so much upon Government support and direction, the Association has acquired another use. It has become a very useful platform for scientists to say what they feel about Government scientific policy. This is a most important function whether it only relieves a bad case of frustration or produces a convincing case for a change.

So much for the past, now I would like to say a brief word about the future. There is no doubt that the years 1957 and 1958 will long be remembered by the Association. In these years a new and wider programme of activity was planned and the money and accommodation to carry it out has been provided.

In the first place, on taking office in January, 1958, the President, Sir Alexander Fleck, announced the intention to form a panel of lecturers to address general audiences on scientific subjects. Already well over a hundred scientists have agreed to join the panel. Area committees have been organised to manage the lecture service. The committees include scientists, teachers, professional organisations and other audience producing bodies.

Secondly, it is intended to form a Junior British Association as part of a wider programme to develop the educational programme for young people. The idea is to arrange meetings on a regional basis, a different centre in each region being chosen each year on the peripatetic model established by the Annual Meeting.

In addition, on the functional side two study groups have been formed. One to look at the metric system and report on the controversial subject of whether it should be introduced in Great Britain. The other to look at the educational system of scientists. This problem is almost as explosive as the former.

I don't suppose it matters very much where a body like the Association has its headquarters so long as there is enough room. For many years the Association has been run from a very congested office in Burlington House. Last year the office was moved to a new building acquired by the Royal Society of Arts. I am particularly concerned that it should be happy and successful in the new offices because I happen to be President of the Royal Society of Arts.

At the beginning I quoted Sir David Brewster's principal objects. To end up with I would like to quote from a report on the functions of the Association issued last year. Amongst other things it says that the Annual Meeting

> should, broadly speaking, attempt to do three things. First, to offer a platform on which leading scientists can discuss their work in all its theoretical complexity. . . . Secondly—for such is the specialisation and fragmentation of science—to encourage scientists to discuss in joint sessions problems in related fields and to develop common problems involved in subjects on the frontiers of present knowledge. Thirdly, to provide for non-specialists—whether they be scientists outside their own field or interested laymen—an annual stocktaking in intelligible language which will review the progress of science and help to make clear its significance and possible consequences.

In my opinion, this last objective is more important than ever. Every human invention or discovery can be used for good or for evil and in the end it is the people as a whole who decide which it is to be. It is therefore essential that the possible consequences of scientific research should be put before the forum of ordinary people. Only in this way can the combined opinion of reasonable, upright and humane men and women throughout the world exert the necessary pressure to ensure that science is used to set free and not to enslave mankind.

SCIENTIFIC CO-OPERATION WITHIN THE COMMONWEALTH[1]

By H.R.H. The Duke of Edinburgh, K.G.

This is the first opportunity I have had to express publicly my very great pleasure at being in Pakistan and attending the Annual Meeting of the Pakistan Association for the Advancement of Science.

My first and very pleasant duty is to read to you a message from The Queen, Head of our Commonwealth:

> As Head of the Commonwealth, I am delighted to take the opportunity of my husband's visit to Karachi to send my warm greetings to all members of the Pakistan Association for the Advancement of Science and my best wishes for the success of their deliberations.
>
> ELIZABETH R.

My second and equally pleasant duty is to bring to all members of your Association the fraternal good wishes of all members of the British Association in the United

[1] Address delivered to the Pakistan Association on February 7, 1959.

Kingdom. I also want to express my personal appreciation to both Associations for making this visit possible and for giving me the chance to see something of science and industry in Pakistan.

We often hear about the invisible ties of friendship and trust which bind together the members of the Commonwealth. We do not hear quite so much about the practical advantages of membership or the amount of quiet unspectacular work which is going on to the mutual benefit of the Commonwealth as a whole.

I must admit that it came as quite a surprise to me to discover the amount of useful co-operation in science which is going on within the Commonwealth today. I was also delighted to find that this co-operation has been active for quite a long time. It's always the same, and I am sure many of you have also noticed that there is no better way of finding out about a subject than having to speak about it.

I. Conferences

One of the first things I discovered was that this Address, the subject of which you chose for me, has come at a most appropriate moment because the very first formal step in scientific co-operation was taken exactly fifty years ago. In the year 1909 the Entomological Research Committee for Tropical Africa was formed with headquarters at the Natural History Museum in London. The funds came from the African Colonies and the United Kingdom and it made the first systematic collection and study of insects injurious to men, animals and crops in East and West Africa.

Although this was a very modest venture, the annual budget only amounted to £2,000, yet it was the start of great things.

The venture was discussed at the Imperial Conference of 1911 and in 1913 it became the Imperial Bureau of Entomology with the two main functions, one 'the identification of all injurious insects sent in by officers attached to departments of Public Health in countries in the Empire' and second, 'to issue a monthly periodical giving summaries of all current literature both British and foreign, dealing with noxious insects, whether agricultural pests or disease carriers'. In the same year it published its first journal of abstracts.

Next, the Imperial War Conference of 1918 established the Imperial Bureau (now the Commonwealth Institute) of Mycology at Kew and it was the Imperial Agricultural Research Conference of 1927 that set up the first Commonwealth Agricultural Bureaux.

In 1933 the Imperial Committee on Economic Consultation and Co-operation met and one of its decisions was that there should be a scientific Conference every five years which, amongst other things, was to review the working of the Commonwealth Agricultural Bureaux.

I apologise for this recitation of historical dates and facts but I am most anxious to make it quite plain that this subject of Commonwealth co-operation in science has been given serious consideration for a good many years by many hard-headed and practical people. I also want to make it clear that throughout the story the endeavour has been to benefit the Commonwealth as a whole and not the particular interests of any one country.

Therefore, to resume the story. The first Commonwealth Scientific Conference and First Review Conference of the Commonwealth Agricultural Bureaux was held in London in 1936 and, as a result, two further bureaux were added. Since then, there have been Review Conferences in 1946, 1950 and 1955. These concerned themselves mostly with finance and administration but the last one recommended that the National Institute of Agricultural Engineering should compile and issue abstracts for Commonwealth use.

At the present moment there are three Commonwealth Institutes and ten Commonwealth Agricultural Bureaux:

Commonwealth Institute of Entomology at the British Museum.
Commonwealth Mycological Institute at Kew (where I opened a new building in 1955).
Commonwealth Institute of Biological Control at the Science Building in Ottowa.

The Commonwealth Agricultural Bureaux deal with the following subjects:

Animal Breeding and Genetics at Edinburgh.
Animal Health at Weybridge.
Animal Nutrition at Aberdeen.
Dairy Science and Technology at Reading (which I visited in 1954).
Forestry at Oxford.
Helminthology at St. Albans.
Horticulture and Plantation Crops at East Malling (which I visited in 1957).
Pastures and Field Crops at Hurley (which I visited in 1958).
Plant Breeding and Genetics at Cambridge.
Soils at Rothamsted (which I visited in 1954).

Each one is attached to an institute or laboratory or University department doing active work in that particular science.

A similar but separate undertaking is the Commonwealth Geological Liaison Office which has been conducting a survey of the mineral resources of the Commonwealth for the past six years. Sixty-five reports have been issued and the Office has now started to review the position of each of the minerals for the second time.

These organisations are probably the most practical and scientifically useful co-operative undertakings in the Commonwealth today. However, that is not the end of the story.

At the 1930 Imperial Conference two Committees were formed to go into the subject of industrial and fundamental standards. This resulted in the Standards bodies of the Commonwealth countries maintaining regular and systematic consultations and in 1946 they met in conference in London and again in 1957 in Delhi. There is every reason to believe that they will go on meeting in future because their work has been most rewarding and is proving very valuable to science and industry as well as to Commonwealth trade.

It's an ill wind that doesn't blow a bit of good in some direction and the last war was no exception. It inspired the formation of the British Commonwealth Scientific Offices in London and Washington. In them work the Scientific Liaison Officers attached to the High Commissioners' or Ambassadors' staffs. They run themselves and a great many other things besides and they are without any doubt the most lively force in Commonwealth scientific co-operation at this moment.

Since the last war there have been five more conferences which between them stimulated a new way of thought and action in the field of scientific co-operation. Perhaps the most interesting one was that which was the outcome of the Commonwealth Prime Ministers' Meeting in 1957. The meeting took place between the 15th and 20th September, 1957, and every Commonwealth country except Malaya was represented. Not all the delegates were nuclear scientists because the main intention of the Conference was to develop a sense of Commonwealth partnership and inter-reliance in the development and application of nuclear energy. For instance, although radioisotopes are produced by nuclear science, they can be used by many other interests—medical, biological and industrial.

In the course of their five-day meeting they did a bit of travelling and visited Harwell, the nuclear power station building at Bradwell, Calder Hall and Dounreay.

They had one non-scientific interlude when the whole party, numbering about 35 delegates, came to lunch with The Queen and myself at Balmoral, and I was delighted to find Dr. Nazir Ahmad and Dr. Ghani among the party.

The latest of this series of Conferences took place when the British Commonwealth Scientific Committee met in Canada in August, 1958. At this meeting Ghana and Malaya took their places for the first time. The meeting decided to abolish the full-scale scientific conferences and substitute regular meetings of the British Commonwealth Scientific Committee consisting of the heads of the national research organisations of the Commonwealth countries. The Committee has decided to meet again in London in 1960.

II. The Colombo Plan

All these Conferences have given point and direction to scientific co-operation, but no discussion on this subject would be complete without a reference to the Colombo Plan, particularly the technical co-operation scheme. The Plan was the outcome of a meeting of the Commonwealth Foreign Ministers at Colombo in 1950. The main part of the Plan deals, of course, with economic matters but under the technical co-operation scheme there is a very considerable movement of students and experts in scientific and technological subjects between Commonwealth countries as well as between other South-East Asia countries and the United States. In the last eight years nearly 7,000 trainees and students have received instruction and just over 1,000 experts have been exchanged between the nineteen countries taking part—eleven of them Commonwealth. Of these only three have not yet received any help and only five have so far been unable to offer any help. That, I think, is ample proof that this is a real co-operative effort.

Just as an illustration, it may interest you to know that, for instance, Pakistan has received help from Australia, New Zealand, Canada and the United Kingdom and has, in her turn, helped Burma, Japan, Malaya, the Philippines and Ceylon.

There are, of course, many schemes being progressed under the Colombo Plan here in Pakistan, but I am particularly interested in the Warsak hydro-electric and irrigation scheme because I hope to see how it is getting on in a few days time. It seems to be an excellent example of Commonwealth co-operation as Canada is providing considerable technical assistance and is footing more than half the bill of 60 million dollars.

III. The British Association

Although, strictly speaking, the British Association is not primarily concerned with scientific co-operation within the Commonwealth, it has played quite an interesting part in the development of science and scientific institutions in Commonwealth countries. As the representative of the British Association at this Meeting I hope you will forgive me if I slip in a few words about that august body's contribution. The fact is that as early as 1884 the British Association held its Annual Meeting for the first time out of the United Kingdom in Montreal, in 1897 it went to Toronto, in 1905 it went to South Africa, in 1909 it was back in Canada at Winnipeg and in 1914 it went to Australia. Since then it has been to Toronto again in 1924 and South Africa in 1929. In each case the report makes it quite clear that the personal contacts which were made at those meetings were considered highly valuable while the suggestions made by the different sections about research projects were almost invariably put into effect. It wasn't a one-way business either. Visitors to the 1897 Toronto Meeting were greatly impressed by the Agricultural Experimental Stations established in Canada and it was recommended that the

Council should approach the Home Government with a view to their imitation in Britain.

Modesty forbids me to suggest that any other Associations for the Advancement of Science owe anything to the British Association but they all have one pleasant feature in common. Members of any Association within the Commonwealth are welcome at any Association's Meetings and every Association makes a point of inviting a delegation from other Associations to its Meetings and that is why I am here today.

IV. Movement of Scientists within the Commonwealth

That then is a very general summary of the history and machinery of scientific co-operation within the Commonwealth but there are, in fact, many other, perhaps more isolated, instances where the fact of the existence of the Commonwealth has affected the course of science.

Perhaps the most convincing example I can choose is the case of Lord Rutherford. Born in New Zealand in 1871, he went to Cambridge as an 1851 Exhibitioner and from there he went to McGill University in Canada as Professor of Physics, where he became famous for his brilliant work on radio-activity. In 1907 he moved to Manchester, where he developed his nuclear theory of the atom and accomplished the first artificial transmutation of matter by bombardment with particles. Returning to Cambridge in 1919, as Cavendish Professor, he saw his prediction of the existence of the neutron realised by Chadwick.

Two others are of particular interest. Sir Ronald Ross was born in India in 1857 and later trained as a doctor in England. Fired by the vision of Patrick Manson, he returned to India determined to find out the cause of malaria. Within three years he pinned it down to the anopheles mosquito and thus paved the way for the control of one of the worst scourges of mankind.

In a different field Sir Claude Inglis is another example. Trained at Dublin, he went to Sind Irrigation in 1906 and thirteen years later he established the first large-scale hydraulic model station in the world at Poona. In 1945 he returned to England to design and direct the Hydraulics Research Station at Wallingford and he is now engaged on the Karnafuli scheme for Pakistan.

There is, of course, an excellent example much nearer home, as Lahore University recently discovered when they lost Professor Salam to Imperial College, London. However, the main thing is that his work on elementary particles will continue to be available to Commonwealth and world science wherever he works in the free world.

This freedom of movement, and the fact that most scientists within the Commonwealth use the same language, are conditions which we should exploit to the greatest extent for the benefit of scientists and through them of science and, ultimately, the people of the whole world.

It has long been recognised that this ability to move about freely within the Commonwealth is a unique advantage and all the conferences on scientific co-operation have stressed the need for a greater movement of scientists between one country and another.

I was particularly interested to discover that this problem was first tackled as long ago as 1890 by the Commissioners of the Great Exhibition of 1851. In the regulations for their Science Research Scholarship it says

> The Scholarships are 'post-graduate', and are intended to enable selected students of overseas Universities who have already completed a full University course and given evidence of capacity for scientific investigation to devote themselves for two years to research work under conditions most likely to equip them for practical service in the scientific life of the Commonwealth.

The Scholarships are tenable anywhere except in the country in which the student has received his scientific education. This scheme was the first of its kind and set the pattern for subsequent awards from other organisations. In 1958 the Commissioners made twenty-five awards.

I am afraid it is not a simple matter to find out exactly how many Commonwealth scientists are in fact studying or working in other Commonwealth countries under some kind of assisted exchange or scholarship scheme. The difficulty arises because the schemes are many and various and are operated by every kind of trust and benefaction.

As far as the United Kingdom is concerned, there are over 500 schemes in operation designed to help people to study and work in that country, and some 124 to send people out of the United Kingdom. Apart from the 1851 Exhibition Scholarships, The Royal Society and The Nuffield Foundation run a bursaries scheme and the British Council runs a Universities exchange scheme.

The same sort of thing is happening outside the United Kingdom. For instance, the National Research Council of Canada offers post-doctorate Fellowships and, since 1948, some 574 research workers from other Commonwealth countries have worked in Canada, and, at the same time, about 40 Canadians each year are enabled to work in other countries. Under the Colombo Plan Australia has taken 2,286 students from South-East Asia between 1951 and 1958 at a cost of £3 million.

Up to thirty years ago the Commonwealth and Colonial Empire looked to the United Kingdom as the scientific centre and no one spent much money on scientific research. However, in the last twenty years alone Government expenditure on research throughout the Commonwealth has risen by an estimated factor of fifteen.

V. Original Scientific Work in Commonwealth Countries

Statistics are well-known to be misleading when handled by amateurs, even experts can make them do strange things, and in any case numbers in science give no clue to quality. Let me just remind you of some of the original scientific work carried out in Commonwealth countries other than the United Kingdom.

For a start it is an interesting fact that no less than 42 Nobel Awards have been won by Commonwealth scientists. But, to be more specific, in 1921 Sir Frederick Banting, working with McLeod and Best in Canada, isolated Insulin. Sir Macfarlane Burnet in Australia has immensely advanced our knowledge of viruses and their diseases. South African workers have recently developed the Tellurometer which measures base lines for surveying by radar in a fraction of the time needed by conventional methods. Also in South Africa Sir Arnold Theiler and P. J. du Toit discovered that lack of phosphorus in the soil was the cause of widespread botulism in cattle. Workers in Australia and New Zealand followed this with their discovery of the importance of trace elements in plant and animal health. Edwards in India developed a vaccine against rinderpest. Scientists in Canada have been fighting a long and unremitting battle against Black Rust in wheat and here in Pakistan research is active in this field as well as in mechanical rice cultivation and in cotton plant breeding, all of which has an international reputation.

The names of Venkata Raman in physics and Ramanujan in mathematics are respected and admired throughout the world.

All this convinces me that the whole Commonwealth would benefit greatly from a larger movement of scientists either as students, research workers, scientific expedition members or as teachers. The important thing therefore is to devise practical and simple machinery to encourage this movement to take place.

The present pattern of scientific co-operation within the Commonwealth can be divided into five parts:

(1) The regular discussion of general scientific problems and of problems particular to the Commonwealth.
(2) The discussion of the problems of administration of science and research.
(3) The regular exchange of scientific information.
(4) The movement of scientists.
(5) Technical help and advice.

(1) and (2) are achieved by regular conferences and contacts between the official research organisations. (3) is achieved by the British Commonwealth Scientific Offices and the Commonwealth Agricultural Bureaux. (4) is achieved by bursaries, scholarships, lectureships and various other schemes of assisted exchange, while the Colombo Plan has encouraged tremendous progress in (4) and (5).

I ought to add at this point that nothing I have said refers to the personal and informal contacts which exist between individual scientists within the Commonwealth. The total of this informal co-operation is probably greater than anything organised through more or less official channels, but of course there are no statistics.

VI. Suggestions to Improve Scientific Co-operation

So far I have only dealt with facts. Now I am going to be rather more rash and put forward some suggestions to increase the amount of co-operation between Commonwealth countries. I will not go so far as to say that these suggestions are possible in practice. I would merely say that they are desirable.

I would like to see the system of the Commonwealth Agricultural Bureaux extended to other sciences and set up in whichever country has the greatest interest in the particular subject. Secondly, I would like to see the system of the British Commonwealth Scientific Offices extended to other Commonwealth countries; this may be a bit premature but, as it is, many Commonwealth countries are doing original research in subjects which are of great interest to others. Thirdly, it would make a wonderful story if countries could pool their resources and plan together the attack on common problems. I say deliberately that it would make a nice story because I don't think scientists or anyone else work that way. It always seems to me that individual laboratories like to attack problems in their own way even though they are quite willing, indeed eager, to discuss the results with anyone who is interested. Therefore, I believe the most we can hope for is a broad agreement about which problems appear to be most important for the time being, followed by a frank exchange of the results of research.

Next I would like to see joint action on scientific problems which affect Commonwealth industry, commerce and trade. Although more than half the Research Associations in the United Kingdom have Commonwealth members and the flow of technical information is not impeded in any way, except if the industries are in direct competition, I am convinced that wider membership of Research Associations and more co-operation between Research Associations in all the Commonwealth countries is both possible and desirable.

However, I am not blind to the complications. Scientists very naturally imagine that anything new which they discover and which seems to them important must be obviously immediately useful to industry. In fact, the most shattering scientific advances may not be of any practical use for many years while some trifling nonsense produced almost by mistake in a laboratory working on, for instance, hydraulics may turn out to be vitally valuable to the boot and shoe industry. Furthermore, even if it can be proved quite easily that a particular discovery will revolutionise cotton farming, it doesn't necessarily follow that cotton farmers will accept and apply the discovery just like that.

For instance, I understand that the Laboratories of the Pakistan Council for Industrial Research have, in fact, completed seventeen processes making use of indigenous materials which are ready for exploitation by industrialists. Some have already been taken up but I wouldn't be surprised to hear the Chairman of that Council say that 'you can lead an industrialist to the waters of science but you can't make him drink'.

There is only one way to ensure the early application of scientific research. It is essential that industry and all other potential users of scientific production should be as closely associated with the research organisation as possible at all times. Industries and farmers must be encouraged to make direct use of research facilities by asking questions and they must also be made to feel a personal interest in the research activities by being asked to take part in experiments and developments.

The rules of human nature are not really very complex. If somebody offers you advice, the chances are you'll tell him to mind his own business; if, on the other hand, he asks you for your advice and help, you are probably rather flattered.

The key to the problem of the application of scientific discovery is the closest collaboration between the research establishments and industry.

VII. Benefits of Commonwealth Scientific Co-operation

So far I have assumed that there is some advantage to be gained from Commonwealth co-operation in science. I have assumed that in the long run the ordinary people of the countries of the Commonwealth will be better off if we make the fullest use of the freedom of movement of scientists and scientific ideas and a common scientific language. However, if this is true, if this business of co-operation is really and practically worth while, and not just a bit of sentimental and comforting eye-wash, there must be some concrete examples which provide conclusive proof. Naturally, I would not have raised this point unless I had that proof.

I think we all agree that where it is possible scientific co-operation should be truly international, and enterprises like the International Geophysical Year, the Organisation for European Economic Co-operation, and, on a smaller scale, the Commission for Technical Co-operation in Africa—South of the Sahara, and the Colombo Plan show that this can happen. Nevertheless, in spite of the wide differences between the circumstances of the Commonwealth countries, the fact that they have similar institutions often makes it possible to organise co-operation on a Commonwealth scale when it is not possible internationally. For example, international efforts were made for years, without success, to organise the preparation of comprehensive catalogues of cultures of micro-organisms. Preparation of such catalogues within the Commonwealth was organised at a meeting lasting three days.

The Commonwealth operates an Index of Translations so that a scientific paper translated anywhere in the Commonwealth is available to any research worker. The Organisation for European Economic Co-operation has so far failed in its efforts to organise a similar index.

To add weight to the argument I have chosen two examples which particularly concern Pakistan. Agriculture is and must remain the most important industry of Pakistan. For many years the soil will remain your main source of wealth. Anything therefore which advances the art and science of agriculture is vital.

After the 1914–18 war investigations were started by meteorologists in England to investigate the behaviour of the layer of air within 100 feet of the ground about which practically nothing was known. The immediate purpose of this work was military; to study the rate of evaporation from the ground of poisonous gases and the travel of gas and smoke clouds. This work has been continued at Cambridge and from measurements of the humidity and wind velocity at different heights an electronic computer can calculate the mean water loss of crops hour by hour. It is

then possible to estimate the water consumption of farm crops by physical measurements of the micro-climate. It is a bit early to say what the practical application is going to be but it shows how scientific research planned for one object in one part of the Commonwealth can produce unexpected techniques and results for other purposes in other places simply because of the working contacts which exist in the Commonwealth.

I hope this matter will be of particular interest to the President of this Association (our Chairman today) whose work on soil science is well known and who now controls Agricultural Development in East Pakistan.

The second example concerns a specific investigation. A model investigation is now in progress at the Wallingford Hydraulics Research Station in England to determine the causes of the changes in the bed of the mouth of the Karnafuli River in East Pakistan so that the conditions at the port of Chittagong can be improved and stabilised. This particular piece of work is being done under the Colombo Plan.

In neither case has there been any question of attempting to gain either economic or political advantage. There has been no question of prestige or personal glory. These two cases are typical of hundreds which are in the pipe-lines of Commonwealth co-operation in science, pipe-lines which should be made to carry information and ideas in both directions between all members of the Commonwealth of Nations.

I do not really believe that anyone can seriously doubt that science devoted to fundamental research and the application of natural knowledge to civil and peaceful ends is capable of bestowing the most wonderful benefits upon mankind. In our own time it has brought about a period of almost headlong industrial and therefore economic expansion. I need hardly emphasise the profound effect which science has had upon medicine and agriculture. (Although the cynic might say that science has simply made it possible for agriculture just to keep pace with the growing demand for food which is a direct result of the effects of improved medical practice.) All the same, there is no use denying that the developments brought about by scientific research have produced a whole host of new problems; problems which can only be alleviated by humane and thoughtful administration; problems which scientists, in company with all other professional groups, must face and overcome as ordinary thinking human beings.

By far the most harrowing problem is the use of science for destructive and warlike purposes. Everyone deplores it but there is obviously no immediate solution. However, I firmly believe that if we can go on building on this foundation of peaceful co-operation between Commonwealth countries in all spheres of activity, we shall be doing much more than simply helping ourselves, we shall eventually have a structure which will give hope and confidence to all the men and nations of the world and then science at last will be freed for ever from the grim necessity to invent weapons of destruction.

SOME PROBLEMS IN THE TROPICAL AFROMONTANE FLORA[1]

by

PROF. W. ROBYNS

THE physiography of tropical Africa is largely dominated and characterised by a number of isolated mountains and mountain ranges forming widely scattered islands of elevation rising almost abruptly out of the surrounding country. Apart from Mounts Cameroun and Fernando Po in the west, they are all located in the east in relation to the two main branches of the Great Rift Valley. They fall into two main groups: the Ethiopian group and the East African group. Three mountains of the last group—Kilimanjaro, Kenya and Ruwenzori—attain a height of more than 5,000 m. and their summits are covered with perpetual ice caps and snow fields, which is most remarkable, especially for Mount Kenya situated on the equator and for Mount Ruwenzori situated just north of the equator. Indeed, on the geographical equator it is possible to pass from the equatorial bioclimate, at the very base of these mountains, through all the intermediates to the cold frost bioclimate, on their summit, in a short vertical distance of only 4 to 5 km.!

Therefore these isolated mountains harbour a range of different vegetation belts, each with a special flora in close relation to their bioclimatic zonation. All have been studied in the last century by a number of explorers and botanists and, recently, O. Hedberg (1951) has given a critical survey of the vegetation belts of the East African mountains: Virunga volcanoes, Ruwenzori, Elgon, Aberdare, Kilimanjaro and Meru. Ascending from the base he distinguished three main vegetation belts occurring on all these mountains (O. Hedberg, 1951, Fig. 4).

1. *A montane forest belt* containing on some mountains three distinct zones:

   (*a*) a montane forest zone,
   (*b*) a Bamboo zone,
   (*c*) a *Hagenia-Hypericum* zone.

2. *An Ericaceous belt.*
3. *An alpine belt.*

These vegetation belts are based on three altitudinal vegetation limits:

(1) the lower limit of the montane forest against the savanna;
(2) the limit between the broad-leaved or coniferous montane forest and the Ericaceous belt;
(3) the upper limit of the continuous Ericaceous vegetation.

It has been pointed out that the first vegetation limit does not exist on the lower, north-western slopes of Mount Ruwenzori in the National Albert Parc, Belgian Congo, where, at about 800 m. height, the equatorial or lowland rain forest of the valley merges gradually through an intermediate transition rain forest into the montane rain forest (W. Robyns, 1948, p. xlix). Before the clearing or the destruction of the transition rain forest by man for cultivation and pasture the same altitudinal forest continuity existed on the other lower slopes of Ruwenzori, on

[1] A paper delivered to Section K (Botany) on August 28, 1958, at the Glasgow Meeting of the British Association.

those of the western Virunga volcanoes and on some slopes of Kilimanjaro and Kenya. It may therefore be sounder to define the criterion for the lower limit of the montane rain forest belt on *ecological* and *floristic* characters rather than on temporary and artificial vegetation limit.

There is some difference of opinion among botanists about the zonal classification of the Bamboo forest, which belongs undoubtedly to the 'pluviisilvae' of E. Rübel (1930), but seems so different from the broad-leaved montane rain forest that it might be considered as a distinct vegetation belt. However, it is sometimes more or less intermingled with this montane forest, as on both dorsal ridges of the central Graben.

The upper limit of the continuous Ericaceous vegetation determines the beginning of what is generally called the alpine belt. On the high tropical African mountains, there is no real forest limit or tree limit comparable to that of most temperate and subtropical mountains. But above the Ericaceous belt, at 3,600 m. to 4,000 m. height according to the mountains, the vegetation and flora suddenly change and, although rather diverse on the different mountains, they consist of some striking oligotherme life-forms and communities, such as the forest-building *Dendrosenecios*, the giant *Lobelias*, the *Helichrysum* scrub, the carpet-building shrubby *Alchemillas* and the *Carex*-bogs. These are closely adapted to a peculiar seasonless bioclimate, which C. Troll (1943) has rightly called a 'Frostwechsel-Klima', with alternating night-frost and day-thaw almost every day of the year. This belt deserves an appropriate name and, pending a better term, *afroalpine*, coined by L. Hauman (1933, 1956), may be used to indicate the topmost vegetation and flora of these mountains, which are ecologically vicarious with the alpine vegetation and flora of the mountains of the subtropical and temperate regions or, according to C. Troll (1948), with those of the subantarctic regions. In the same way, the term *afromontane* may be used for the whole montane vegetation and flora of the tropical African mountains.

Consideration will now be restricted to a general study of the '*afromontane*' flora and, within the space available, will be restricted to some fundamental problems.

First, it may be emphasised that the tropical '*afromontane*' flora, at least at high level, is likely to be *entirely natural*, as it has never been disturbed by human beings, for whom the high mountains, such as Ruwenzori, were entirely taboo. This exceptional situation, which also applies to the fauna, provides especially appropriate and favourable opportunities for scientific study, although its great interest has not been fully realised by scientific investigators in tropical Africa.

The tropical *afromontane* flora is mainly composed of orophytes occurring mostly above 1,600–1,800 m. height, but descending sometimes in the low country or the plains. Our knowledge of this flora is comparatively recent and is still far from complete, even for the most actively studied Spermatophytes. Recent and satisfactory statistical data are available only for the Spermatophytes of western Ruwenzori and the Virunga volcanoes, the flora of which comprises, according to W. Robyns (1947–55), a total of 1,182 species, belonging to 475 genera and 114 families. There is only one Gymnospermae, but the Angiospermae are represented by 288 species of Monocotyledons against 893 species of Dicotyledons, which gives a ratio of 1 : 3, indicating an environment especially favourable to Dicotyledons. Among the latter, there are 437 choripetalous and 456 sympetalous species, giving a ratio of about 1 : 1. If these categories are considered from the western Ruwenzori alone, they are respectively: 128 Monocotyledons against 470 Dicotyledons, or a ratio of 1 : 3·67, still more favourable to Dicotyledons; and 217 choripetalous against 253 sympetalous species, giving a little surplus to the latter. The altitudinal distribution of most of these species is comparatively well recorded.

The comparative study of the whole tropical *afromontane* flora has revealed some striking similarities and affinities between the different isolated mountains, involving several really interesting and, at the same time, very complex biological problems in *taxonomy*, *chorology* and *history* or *origin*.

1. Taxonomic Problems

The taxonomic treatment of herbarium material is by no means easy, even if the specimens are complete and suitably labelled. It is not uncommon that widespread species, distributed all over the tropical African mountains, have been described independently several times, so that a critical revision of the type material is necessary to settle their nomenclature.

Often the montane species display a great range of variation in correlation with the diversity of ecological factors in altitude on the same mountain or on different mountains, which has resulted in what has been called 'excessive splitting' of species, mostly based on one or two herbarium specimens. When enough herbarium material is available, it has been possible in some instances to determine the nature and the range of such ecological variation and to reduce to synonyms some related specimens representing only different stages of a continuous series. *Podocarpus milanjianus*, a Pan African montane tree, extends from 1,900 m. in the montane forest up to 3,200–3,500 m. in the Ericaceous belt. Abundant herbarium material shows its continuous variation from a large tree at the lower altitudes to a small tree, or even a more or less ericoid shrub with congested leaves at high level. A similar behaviour is to be encountered in *Philippia johnstonii*, endemic on Ruwenzori and the Virungas. Among the herbaceous taxa, it occurs in *Swertia kilimandscharica* on the East African and Ethiopian mountains, in *Poa leptoclada* and *P. schimperiana*, in *Festuca abyssinica*, in *Luzula abyssinica* and in several others which have recently been thoroughly revised by O. Hedberg (1957).

Among the other complications in taxonomy, O. Hedberg (1956, p. 482) mentions hybridisation. This problem, which is by no means restricted to the tropical *afromontane* flora, is one of the greatest troubles of the taxonomist, who is often unable to demonstrate it accurately. It cannot rightly be solved without careful field studies and experimental work and it need not be emphasised here that this is very difficult, if not impossible, on tropical mountains especially at high altitudes.

2. Chorological Problems

One of the salient features of the tropical *afromontane* flora, which still deserves a careful study, is the large number of local endemics occurring on each mountain.

However, the great 'mystery' of this flora centres about the *discontinuous geographical distribution* of many taxa and the occurrence of *geographical vicariism*, both of which require separate treatment on a much larger scale than is permitted here.

Discontinuous geographical distribution means that the distances between the different parts of the total area of a taxon are so great that no direct actual exchange of diaspores may occur. The horizontal distance from Ruwenzori to the Virungas is about 160 km., to Elgon about 540 km., to Kenya about 830 km. and to Kilimanjaro about 900 km. Notwithstanding these gaps, many genera and especially species appear to be common to all, or to several, of these mountains where they occur mostly in the lower belts. In the *afroalpine* belt they are much fewer on account of the general tendency to specialisation. It seems useless to give here examples, which can easily be found in most genera, but particularly in *Alchemilla*, *Philippia*, *Lobelia*, *Helichrysum* and *Senecio*. Besides these strictly African elements, some of which extend also to Mounts Cameroun and Fernando Po, several afro-orophytes are pluriregional elements, or even sub-cosmopolitan to cosmopolitan elements, such as *Poa annua*, *Capsella bursa-pastoris*, *Oxalis corniculata*, *Anthriscus*

silvestris, *Sibthorpia europaea*, and many other species, along with some ferns such as *Cystoperis fragilis* (L.) Bernh. and *Asplenium adiantum-nigrum* L., some mosses such as *Bryum argenteum* and *Hypnum cupressiforme*. Again these temperate types are not strictly confined to the alpine belt; some occur rather in the lower belts, as G. Taylor (1937) has already observed.

Another striking chorological feature in this *afromontane* flora is to be found in the occurrence of geographical vicariads exemplified by the well-known fact that actually closely related taxa inhabit mutually exclusive areas. Vicariads are based mainly on taxonomical evidence, which may differ from author to author, as is actually the case for the polymorphic *Philippia trimera* Engl., treated separately and in a different way in 1957, both by O. Hedberg (1957, pp. 144–6, and pp. 298–301), and by R. Rose (1957, pp. 737–9). Such discrepancies being the result of the great variation of montane populations and of the difficulty to decide whether they are discontinuous or not, show clearly the immense complexity of geographical vicariism. Here also experimental work could be a great help.

Horizontal vicariads may occur at species level, for example *Lobelia wollastonii* (Ruwenzori and Virungas) and *L. telekii* (Elgon, Aberdare, Kenya); *Subularia monticola* representing on the tropical African mountains the cognate temperate *S. aquatica*. However, it appears more frequent at the subspecies and the varietal level. Good examples of these are, *Alchemilla argyrophylla* (Aberdare, Kenya, Kilimanjaro) and *A. argyrophylla* subsp. *argyrophylloides* (Ruwenzori); *Valeriana kilimandscharica* (Kenya, Kilimanjaro), *V. kilimandjarica* subsp. *elgonensis* (Elgon) and subsp. *aberdarica* (Aberdare); *Deschampsia flexuosa* (holarctic and South America) and its var. *afromontana* (Ruwenzori, Virungas, Elgon, Kenya, Kilimanjaro, Meru).

Altitudinal vicariads may be illustrated by *Lobelia giberroa*, representing the *afroalpine* giant lobelias in the lower montane forest and in the ericaceous belt; by *Senecio transmarinus*, in the same belts, and *S. mattirolii*, only endemic in the *afroalpine* belt of Ruwenzori; by *S. erici-rosenii* of the Ericaceous belt of the Virungas and Ruwenzori, as a vicarious element of the *afroalpine* Dendrosenecio of the same mountains.

3. Historical or Genetical Problems

The tropical *afromontane* flora comprises several distinct phytogeographical elements, as has been shown by R. Potier de la Varde (1955) for the mosses and, more recently in some detail by J. Lebrun (1957), for the Spermatophytic flora of western Ruwenzori, but it possesses nevertheless a comparatively large *basic stock of common taxa*. Althought detailed phytogeographical analysis is fundamental for the problem of the origin of a flora, it is not possible to treat this difficult subject in detail here. There is only opportunity for attempting to give a short survey of the different hypotheses advanced to explain the origin of this heterogeneous flora with its endemic, its discontinuous and its vicarious taxa.

Several authors merely admit that the tropical *afromontane* flora, and especially the *afroalpine* flora, is at least of Tertiary origin. According to O. Hedberg (1957, p. 376) it is permissible, on the available evidence, to admit two generalisations:

(1) that at least the majority of the members of the *afroalpine* flora have had their later history in common;
(2) that the different enclaves of *afroalpine* biota must have been isolated from each other for a comparatively long time.

The occurrence of a large number of local endemics and the actual discontinuous areas of many taxa may point to the relict nature of the whole tropical *afromontane* flora, but this can only be finally demonstrated by relevant evidence of earlier and greater distribution from fossils or from palynological facts in relation to earlier

bioclimatic changes. In fact, fossils are rather scanty in tropical Africa and palynological studies have only recently been started by O. Hedberg (1955). Finally, the paleoclimatology of tropical Africa is also insufficiently known.

If the ancient character of this ecologically isolated *afromontane* flora is nevertheless assumed, the actual gaps can be explained in different ways which may be grouped under two main heads.

1. In the case of a *polytopic* origin, the isolated populations of each species originated in different centres, and independently of each other, either at the same epoch or at different epochs on the isolated mountains, excluding migration for long distances. Vicariads may have evolved in peculiar environments through increasing geographical isolation resulting finally in the formation of local endemics which might be of comparatively recent origin and might represent progressive forms.
2. In the case of a *monotopic* origin from one centre, migration was of course necessary to allow each taxon to reach its full area and several factors may have been involved.
   (*a*) The spread of diaspores, especially by dust devils or whirlwinds, which are of great importance for the transport of spores, and of light fruits and seeds, for long distances in all tropical countries, and which have mostly been neglected by biologists (J. B. Gillett, 1956, p. 464). This factor may still be effective at the present, especially between mountain groups as is the case for the different volcanoes of the Virungas, or for mountains only separated by small distances such as Kenya and Aberdare, or Kilimanjaro and Meru. However, it seems very questionable for the actual transport of diaspores, between the East African or Ethiopian mountains and Mounts Cameroun and Fernando Po, separated by the whole Congo Basin.
   (*b*) Migration might have taken place in earlier periods when some general lowering of climate to levels cooler than the present has made possible the spread over large areas of which the actual mountain tops are only relicts. In favour of this most current hypothesis, several authors have advanced some evidence of vicissitudes of climate in tropical Africa, at least during the Pleistocene Ice Age.

According to A. S. Boughey (1957), the mountain flora of tropical Africa derived, together with the temperate flora of what is now South Africa, from an original floral unit differentiated in the cooler areas of part of Gondwanaland during the Triassic and Jurassic periods. By various subsequent orogenies and climatic changes portions of the ancient temperate flora were finally isolated on a number of scattered high African mountains, where they became more and more stabilised.

Conclusion

In conclusion, it might be said that all the problems touched upon are among the most complex in the field of African botany about which there has been much speculation supported by only a few well-established facts. It is actually quite impossible to make even a choice between the different hypotheses presented, each of which may have played a more or less important part in the origin and history of the tropical *afromontane* flora. It must be emphasised once more that here, as elsewhere, our knowledge of biological facts is still very unsatisfactory in all long-term problems in which the *historical* factor or the *time* factor is involved. Furthermore, a valid explanation of the origin of the whole *afromontane* flora, as well as of the whole tropical African flora, must be supported not only by an exhaustive study of the biogeography of the vascular plants, but also by that of the non-vascular plants, which constitute probably a greater part of the total flora than is generally assumed and which are mostly still unknown.

The same applies to the study of the different relationships between the *afromontane* flora and the lowland forest and savanna flora of tropical Africa, the historical development of which cannot be treated separately.

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SOME REFLECTIONS ON THE PROFESSIONAL EDUCATION OF TEACHERS[1]

by

PROF. W. O. LESTER SMITH, C.B.E.

I

No country has done more than Scotland for the status of teachers and their professional education. To air my views about such questions here is a presumption and I intend, as far as possible, to restrict my observations to problems that beset us south of the Border. But, although the Tweed is a broad river, it does not prevent Scotland and England having a good many problems in common. There was, for example, a very familiar ring when, just at the close of the last session, Parliament debated education services in Scotland. Miss Herbison drew attention to Scotland's need for teachers, gave some grim figures of overcrowded classes, and described the situation as 'serious, almost tragic' for the future of children now passing through the schools. The Secretary of State, replying, agreed that 'staffing was the crux of the educational problems of the day', and indicated some of the steps being taken to alleviate the shortage.

In England and Wales it is no less the crucial problem. Under existing regulations no class in a primary school should have more than 40 children, and in secondary schools the prescribed maximum is 30. But in actual practice about one-third of the children in primary schools are in classes of over 40, and about two-thirds of the secondary pupils are in classes of over 30. Such shortages not only affect, as Miss Herbison said, the children now in the schools, but they, also, constitute the greatest of all obstacles to educational advance. Correspondence recently published gives some idea of the extent of the need for more teachers. First, there was a letter addressed to the Minister of Education by Sir Geoffrey Crowther, the Chairman of the English Central Advisory Council for Education. This showed that if the two main reforms of the Education Act of 1944, not yet implemented, are carried out—the raising of the leaving age to 16 and the establishment of county colleges —and oversize classes are reduced to prescribed standards, something like 90,000 more teachers will be needed by 1970 than the 247,000 in service in 1956. Last month another letter was published—one written by Sir Philip Morris, Chairman of the National Advisory Council on the Training and Supply of Teachers in England and Wales. This dealt, not with the reforms referred to by Sir Geoffrey Crowther, but solely with the number of teachers required to abolish overcrowded classes and had regard also to the introduction of a three-year course in training colleges in 1960. It asked for an immediate expansion of training colleges, putting its minimum requirement at 16,000 extra places by the autumn of 1962; and it said that the Council 'confidently expected' that an adequate supply of candidates would be forthcoming to occupy these additional places.

So south of the Border our present thoughts about school education are dominated by this unceasing, persistent need for more and more teachers. But Britain is by no means the only country with urgent staffing problems; it would be nearer the truth to say that teacher-shortage is almost a global question, a general characteristic of this mid-twentieth century. Indeed, as Mr. Podsnap might say, our position is a good deal healthier than that of other countries. Many of you will have enjoyed,

[1] Address delivered to Section L (Education) on September 3, 1958, at the Glasgow Meeting of the British Association.

as I did, Mr. Kenneth Richmond's graphic account of his American tour in his book, *Education in the U.S.A.* He has a fascinating chapter on the Teacher's Place in American Society but he tells the naked truth about the supply position. 'Obviously', he says, 'the gap between supply and demand is steadily widening; and when it is recalled that the number of sub-standard teachers in employment is extremely high and that already many schools are faced with double shifts, the outlook is decidedly grim'. Prof. Campbell Stewart in a long article in *The Times* gave his impressions of staffing conditions in Canada after a long tour of schools in that great Dominion and he, too, had a somewhat dismal story to tell, both of shortages and the employment of sub-standard teachers.

Similar accounts come through from beyond 'iron curtains', while in those under-developed countries, striving to forge an up-to-date system in a hurry, the staffing problems are as acute as they could be. And so they are in what we still inaptly call 'the Colonial territories'; of them Sir Christopher Cox well said in his Presidential Address to this Section two years ago: ' . . . in most territories the demand for schooling has now reached a stage of intensity at times almost obsessional in its strength.'

II

When analysing the demand for more teachers, we usually attribute it to 'the bulge', the later school-leaving age, the tendency to stay longer at school and other factors that can be assessed numerically in statistical tables. But those are the occasions rather than the causes of the demand, which is surely a product of the social and technological revolution of our time. In the highly developed as well as in the emerging nations the urge for education is—to use Sir Christopher's apposite phrase—'almost obsessional': and it is broadly based. Parents insist upon good schools for their children, and statesmen regard them as essential to a nation's survival. Sir Winston Churchill has expressed the modern statesman's view in words that will live in history: 'The future of the world is to the highly educated races, who alone can handle the scientific apparatus necessary for pre-eminence in peace or survival in war.' That is a judgment to which the statesmen of all leading nations would readily subscribe without any summit conference.

Some will ask—and not without some justification—whether we can reasonably hope to recruit teachers for our schools of suitable calibre in such increasing numbers. The demands of industry, commerce, and the civil service for intelligent, well-educated personnel grow every year, and there are also the competing claims for specially qualified teachers from the expanding universities and technical colleges. The official view on this point is that an adequate supply of suitable recruits 'can be confidently anticipated', and the latest news from the colleges suggests that the quality of those who will enter this month compares favourably with that of recent years. This good prospect is largely due to the developments that have taken place since the Education Act of 1944 began to operate, and especially to the increasing numbers staying on at school after 15 and the consequent growth of sixth forms.

There are sceptics who doubt whether we shall be able to find the large numbers of intelligent and educated citizens that industry, commerce, and government services will increasingly require. If we should fail in this respect, it would not, I think, be due to lack of natural talent. There is an ample reservoir of ability but we must have a strong teaching force if we are to make good use of it. For this reason, it is important to recognise in a much more practical way than we have yet done the vital place of the teacher in the national economy. We cannot, for example, afford to let our schools go short of good teachers of mathematics and science; we cannot, indeed, afford teacher shortages of any kind if we desire the pre-eminence of a highly educated nation.

The need, therefore, is not just one for more and more teachers. Quality is of paramount importance, and this is as true of the primary schools as it is of the secondary; for it is there that foundations are laid and interests first kindled. It is good to have the magnificent new schools that are becoming such conspicuous features of our modern landscape: yet, if they are staffed with teachers unequal to their opportunities, their labour is but lost who build them. So we have to achieve the difficult operation of increasing numbers and raising standards at the same time. Foreseeing this problem in 1944 the McNair Committee urged England and Wales to follow the Scottish example, and provide a three-year course in their training colleges instead of the hectic two-year course which has for long been normal. At long last this essential reform has been officially accepted, and our Institutes of Education and Training Colleges have been actively engaged in planning the scope and content of the lengthened course with a view to its introduction in 1960.

With a third year the temptation to add subjects to the curriculum will be strong, but so also very fortunately is the resolve to resist it. There are already too many bursting portmanteaux in our educational world, the result of desperate efforts to make the curriculum keep pace with the proliferation of subjects. When pressing for a three-year course the McNair Committee made it very clear that its purpose would be frustrated if it was used mainly 'as an excuse for a general increase in the number of subjects'. And happily the view prevails that much of the uncommitted time should be available for discussion, reflection, and cultural interests.

A three-year course can be no more than an introduction to an exacting vocation. As the McNair Committee wisely said, it should be 'planned and conducted in such a way that at the end of it the student realises that, far from his education being complete, he is about to enter upon its most significant stage which depends upon his own initiative and effort'. Hence the great value, especially at a time of change in so many spheres of knowledge, of in-service courses and of opportunities of seeing developments in other schools and in other countries.

III

But just as we have to aim at accomplishing such apparent opposites as quantity and quality, so in our planning of the curriculum we have to strive for diversity as well as depth. One glance at the many pages of advertisements of teaching posts in any educational journal that enjoys a wide circulation is enough to bring home to us the amazing diversity of demand. In totalitarian countries they try to solve the intricacies of demand by direction, while we with our strong tradition of freedom regard right of choice as the birthright of every individual. This partly accounts for the fact that of the 2,500 graduates training in university education departments only 580 hold degrees in mathematics or science. But the needs of the nation cannot be ignored, and in a report on *The Scope and Content of the Three-Year Course* the National Council on the Training of Teachers in England and Wales offers this advice about the students' selection of the main course of study:

> The student must have the maximum freedom of choice, though he may also need guidance, in the selection of his main subject(s). But this freedom cannot be absolute, for the student is being trained for a career of teaching in the schools. It follows that the needs of the schools must influence the training that he is given. Taking the country as a whole, the spread of subjects in the colleges must be related to the subjects taught in the schools and, within limits, the number of students taking a subject must be governed by the number of teachers of that subject the schools need. What has been said implies some degree of planning, both within the area training organisations and nationally.
>
> Some planning, too, there must be of the distribution of main courses among the different colleges. But, by and large, we seek to solve this problem by relying on the good sense of students, and the co-operation of universities, training colleges, and

schools. The problem has now become acute, for we have reached a stage in the implementation of the Education Act of 1944 when success or failure almost hinges on our ability to match year by year the very diverse staffing requirements of the schools.

IV

It would, however, be a sorry preparation for teaching if the College course was excessively devoted to specialist studies and the acquisition of professional skills. Personally, I do not think there is much danger of this, for in the preparation of teachers for their vocation University Education Departments and Training Colleges do their utmost to help students to become what John Stuart Mill called 'capable and cultivated human beings'. The importance of this and of the community life of the colleges, as a means to that end, can hardly be exaggerated: for teachers are custodians of our ideals and involved directly and indirectly in moulding the pattern of our citizenship in this technological age. One of the great problems of our time, on which they can exert great influence is the culture of our democratic society, and its use of the many inventions that technology places at our service. Matthew Arnold showed a prophetic understanding of this crucial problem when, foreseeing the dawn of a Welfare State, he wrote: 'Many are to be partakers in well-being, true; but the ideal of well-being is not to be, on that account, lowered and coarsened.'

The contribution that teachers will make to the society of tomorrow will be largely influenced by the way they are prepared for their task. That is why the minor revolution now in process in our training colleges is so important. It will be accelerated by the proposed expansion, which in turn will provide opportunities of strengthening the staffs of the colleges in ways that will help them to equip teachers for the needs of our time. The sciences will figure more prominently in their curriculum but not, I think, to the detriment of the humanities. Like Nature, education does not, even in revolutionary times, change by leaps and bounds, but there are at present several new trends. Of these one of the most significant is the growing realisation that science and technology can be, and should be, taught as humane studies. There are unmistakable signs of a swing away from the traditional view. Let me by way of illustration conclude with two examples of this that come from quite different sources.

First, the Science Masters' Association which in a recent policy statement contends that Science is a humane study. 'The schools, therefore,' it asserts, 'have the duty of presenting science as part of our common cultural and humanistic heritage. . . . Such a presentation will help to produce a climate of opinion in which science can flourish, and in which scientific advances can be applied for the common good.' For my other example I would like to take you to Durham Cathedral where the Archbishop of York recently made the centenary of a Training College an occasion for preaching a sermon on the humane potentialities of the sciences. 'Not only,' he said, 'is the great scientist commonly a most humane person, but the craft of the scientist involves the human qualities of faith and imagination.' So he pleaded for an end of the cleavage between the humanities and the sciences, and urged that in the education of teachers 'both these disciplines should be included within the study of the wonder of man in his mysterious being'.

RURAL SETTLEMENT IN IRELAND AND WESTERN BRITAIN[1]

INTRODUCTION

By E. Estyn Evans

At the Glasgow meeting of the Association a joint-session of Sections E (Geography) and H (Anthropology) was held on the morning of Tuesday, September 2, 1958, when four papers were presented on problems of early rural settlement in the major regions of Western Britain and Ireland. Prof. H. J. Fleure, a past-president of both Sections, was in the chair, and the sectional presidents—both of whom had graduated under him at Aberystwyth, were also on the platform. Shortened versions of the papers presented are printed below. Dr. Horace Fairhurst (Dept. of Geography, University of Glasgow) relates the dispersed settlement pattern of Western Scotland in the Dark Ages to the physically fragmented countryside and to a pastoral economy. Dispersion, however, does not necessarily mean 'single-farms'. In historic times the typical rural settlement was a cluster of farmsteads (clachan) occupied by tenants who farmed the township lands jointly in in-field and out-field. The extensive hill pastures were utilised for summering cattle under a system of transhumance. The scattered farms and cottages of the present landscape are rarely older than 1750.

Dr. Bruce Proudfoot (Dept. of Geography, Queen's University, Belfast) shows that the clachan type of settlement, with accompanying open-fields, was widely distributed in Ireland down to recent times, and although Dark Age evidence is scanty he equates the settlement-type with the townland and with plebeian cultivators who were subordinate to the free minority farming from their 'raths'. Mr. Glanville Jones (Dept. of Geography, University of Leeds), dealing with Wales, finds Dark Age evidence of similar house-clusters (bond-hamlets) and open-fields which were, however, largely replaced by isolated farms and enclosed fields by the sixteenth century. In addition, there were the settlements of the freeman disposed in open order around the edges of their open-fields. These, too, had been enclosed by the sixteenth century. The freemen were a priviledged minority, and though their economy was predominantly pastoral he finds no evidence for semi-nomadic tribalism. W. L. D. Ravenhill (Dept. of Geography, University of Exeter), discussing the evidence for Cornwall and Devon, confines himself to an analysis of sites. He rejects the view that there was a fundamental distinction between upland Celtic and lowland Saxon sites, and argues for continuity from pre-Roman times into the Dark Ages.

Prof. Fleure, in his introductory remarks, commented on the new approach to settlement studies which had emerged in recent years, thanks in considerable measure to work in Celtic lands, where historic records were few or had been incorrectly interpreted. Geography and archaeology had joined hands in the field in the search for fresh evidence. Half a century ago the monumental work of August Meitzen had popularised the view that dispersed and nucleated settlements could be traced back to different ethnic groups; and the association of Einzelhöfe with the Celtic lands was regarded as a feature of long standing. A quarter of a century ago, on the other hand, it was fashionable to explain settlement types in terms of the physical environment (e.g. the abundance or scarcity of water) and of types of farming (e.g. crop-husbandry and stock-raising). It was generally held that pioneer

[1] Shortened versions of the papers presented have been prepared for publication by Professor E. Estyn Evans.

farming with nucleated settlement was restricted in prehistoric times to land that was fertile but free of heavy forest, and that the stock-raising tradition of western-most Europe, with its need for enclosed fields, had been associated from the beginning with isolated farms established in forest clearings. It seems clear, said Prof. Fleure, that we must reckon both with cultural traditions and with environmental forces. The problems of rural settlement were being viewed in a new light with the better definition, in space and time, of prehistoric cultures. The need now was for many local studies approached with a longer and wider historical and geographical perspective.

When the present writer began working on rural settlement in Donegal twenty years ago he was unaware that an 1845 map of a town-land in the area he was studying had been published and copied by many authors, including Meitzen. It was curious to see how this map, with its clachan and open-fields, had been explained away. By the time we come to Henri Hubert (*Les Celtes, etc.*, 1950, 262) Irish open-fields are interpreted as a suburban settlement-type, no doubt through a misunderstanding of the word 'townland'. There has been great reluctance, in Ireland at any rate, to abandon the view that the Celtic lands were anciently enclosed and settled in single-farms, partly because it was a flattering alternative to charges of nomadism and tribalism. The clachan, as far back as can be traced, was a small group of farmsteads occupied by blood-relations who were bound by various ties to an élite. It may be that in Ireland this élite—originally the Celtic overlords—lived in single farms, but G. R. J. Jones shows that in Wales the settlements of the freemen became 'isolated' only after enclosure of the open-fields in the fifteenth and earlier centuries.

Evidence for the antiquity of some kind of open-field agriculture and nucleated settlement in Celtic lands is accumulating, but it was much simpler and more flexible than the two- or three-field system of the English lowlands. It has survived not infrequently, in Ireland and Scotland at least, down to the present day, and one must pose the question, raised by H. L. Gray, as to the extent of its survival into the post-Roman and historic periods in lowland Britain.

WESTERN SCOTLAND

By Horace Fairhurst

Circumstances combined from an early age to favour a basically dispersed type of settlement in Western Scotland. From the physical point of view, the fragmented nature of much of the countryside broke up the better lands so that wide stretches of fat acres were rare, especially in the days before an agricultural technique capable of dealing with cold clay lands had been developed. Peat formation, too, has tended to blanket much flat and gently sloping ground. Stock raising has been at a premium in a region where the wet harvest period is proverbial, and this again has not fostered settlement in larger village units. Social tradition seems always to have had a bias away from the agglomerated type of settlement, though little can be said of the period before the end of the Bronze Age owing to extremely limited evidence.

In the Iron Age, there were established in the west a large number of small isolated settlement units housing little more than two or three families. These take on a variety of form which continues to puzzle and indeed to bemuse the archaeologists. Most characteristic is the small dun, usually a walled enclosure not much more than fifty feet across, though excavation as at Kildonan and Ugadale (1) has shown that at least some continued in use to the fourteenth and even the sixteenth centuries, and some may date to the Dark Ages following the Roman Occupation.

The same is true of the crannogs, which consisted of a circular timber homestead on an artificial island in some shallow loch; Buston in Ayrshire belongs to the Dark Ages. In the Hebrides, wheelhouses seem to be the equivalent of the wooden house, built in stone and often set partially below ground level; they date to about A.D. 200, but the pottery suggests a life of several centuries. In the windy north-west, too, there is a scatter of broch towers, at least as far south as Mull; internally they are too small for more than a very few families. Some seem to have been reoccupied by wheelhouse folk, but the brochs persistently remain a problem both in date and function.

Hill forts are rare in the west as compared with the south-east; traces of roughly circular dwellings have been found, e.g. at the Meikle Reive (2), but the amount of occupation material obtained in excavations has been so meagre that their true purpose is still problematical. A very few examples in the west indicate a larger settlement unit still; Carman behind Dumbarton has a number of hut circles and covers several acres.

In a sense, the Dark Ages in the west seem to have lasted until about the eleventh century. Apart from a few nuclear forts such as Dunadd and Dunbarton and a number of sites typical more of the Iron Age which continue as part of the settlement pattern, one cannot point to a single domestic site and say with conviction that it is characteristic of the Dark Ages. Yet it is to this period we almost inevitably turn for the foundations of the settlement pattern of later times. Almost certainly, many sites of this period have been obliterated in what is the farmed land of today (3).

The feudal period which followed the establishment of a united Scotland, from the twelfth century onwards, saw many important changes, but of the detailed pattern of rural settlement, information remains extremely scanty. The burghs, as Miss Grant suggested (4), seem to have inhibited the growth of true villages. From a geographical point of view, however, the burghs for long remained very small (and the burgesses were much concerned with farming) so that in fact they formed part of what was then a one and indivisible settlement pattern.

In general, the rural population was dispersed down to the eighteenth century. In detail, much minor variation must have occurred. The unit of settlement was quite small and it must be remembered that stock rearing was always of great importance in the economy. A township or *baile* (5), comprising arable and pasture, was occupied by one or more groups of tenants who farmed the land jointly; each group numbered usually between two and eight though with variations above and below. The arable was divided into in-field and out-field, and strip cultivation appears to have been universal, with one man's holding in a number of separate rigs (6). The dwellings were in clusters at some place or places within the township, made up of the farmsteads together with the cottages of several labourers. Such clusters are rather large to be called hamlets, but too small for villages. The word 'clachan' is appropriate for the Highlands and is often used more generally, but a Lowland expression was 'ferm toun'.

Most of our reliable information on the old order relates to the very eve of the Agrarian Revolution when disintegration and change had already occurred. An obvious approach to the study of the form and age of the older settlements, which has so far been neglected, is excavation. Deserted Highland clachans, at least, occur in great numbers and Roy's map is invaluable in their study; the problem is to see where, with excavation, one could hope to find the early or even the original forms of the dwellings. Moreover, locations may well have changed considerably before the eighteenth century.

The great difficulty in studying the older settlement pattern, is the radical transformation of the countryside which occurred in the eighteenth and early nineteenth centuries. Our present farms and villages, together with the fields that

go with them, are to a very large extent the creation of modern times. It is astonishing to find how few of our rural cottages in the Lowlands date back to before 1750, and it is often extremely difficult accurately to locate the old ferm touns without detailed research (7). The radical reorganisation was both later and less thorough in the Highlands and especially in the north-west, where even now an occasional blackhouse may still be inhabited; until quite recently, too, the custom prevailed of taking the cattle away to summer pasture where a few herds lived for some weeks in the shielings, which were temporary dwellings reminiscent of the Iron Age.

With regard to the crofting communities of the north-west, a word of caution is necessary. The arable land, as in parts of the Hebrides, may still be cultivated by strips, even allocated periodically, with communal grazings on the hillside or machair. This might readily suggest to the uninitiated a direct survival from the remote past, but as the Crofting Survey of the Geography Department in Glasgow University proceeds, it becomes increasingly evident that rarely, if ever, can such a direct survival be envisaged. The townships may exist much as before, old dwellings continue in use, but time and again, the old order was changed in the eighteenth or nineteenth century, and then, later, the land was reallocated to form the present crofting communities.

The transformation of the Scottish countryside has been so radical that in general, geographers have rarely been forced or tempted to look further back in their regional studies than the eighteenth century. The modern settlement, however, was an adaptation from an age-old order, and it is obvious that the study of settlement would benefit enormously if the archaeologists could extend their interest into times anything but prehistoric, and equally, if geographers could push back regional studies beyond the eve of the Agrarian Revolution.

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IRELAND

By V. B. Proudfoot

The clachan is defined here as a cluster of farmhouses and associated outbuildings usually grouped without any formal plan. Clachans were formerly widespread in Ireland, and were often associated with open-fields, as Evans pointed out in his now classic paper in *Geography* in 1939 (1). He showed that in parts of Donegal at least the present-day scattered farmsteads with their long strip farms were mainly the result of nineteenth-century land planning. In the early decades of the nineteenth century clusters of some thirty to forty houses had been common in Donegal and of these some groups of up to a dozen houses still survived. In most clachans

the inhabitants were related to each other. They enjoyed common rights of grazing and peat cutting on the unfenced mountain lands. They cultivated the lowland soils under an open-field system. In the open field or fields associated with each clachan individual farmers held their land in scattered strips or plots, which were sometimes periodically cultivated—like the Scottish in-field—while other land, cultivated according to some crude rotation such as a two-years' crop followed by two years' fallow, was analogous to the Scottish out-field. The system of landholding was often referred to as rundale.

In 1939 it was suggested that the clachan and the open-field system might well be features of considerable antiquity, perhaps indeed survivals from pre-Celtic times. This year, in his Presidential address to Section E, Prof. Evans has returned to this theme, recognising such features of rural life in many of the Atlantic ends of Europe. In the years between, many studies of Irish rural settlement have been carried out, especially by those who have studied at Belfast under Prof. Evans. Mention should be made here of Buchanan, Johnson and McCourt: to them, to Prof. Evans and to Mr. Sean MacAirt of the Department of Celtic at Belfast, I am deeply indebted.

The commonest forms of settlement, remains of which have survived from the Irish Dark Ages, are the raths or ring-forts and cashels. Characteristically these are small, often circular, enclosures, which were the farmsteads of small virtually self-sufficient households. There is little evidence for the production of an agricultural surplus, so that the areas farmed were probably relatively small—perhaps of the order of 60 acres.

In County Down the raths are unevenly distributed over the farmlands of the county, dense in the west, less so in the east. Accepting a figure of 60 acres as the size of the typical rath farm, and eliminating lowland areas of bog and heavy soils and of rock outcrops, there are large areas of fertile land unaccounted for, especially in the east. However, in this area there is the greatest concentration of early churches, and the capital of the county—Downpatrick—is built alongside a hill-fort occupied continuously from the late Bronze Age to the Middle Ages. It seems unlikely that the distribution of raths in this area reflects the actual distribution of population, for this area can never have been empty of population in early Christian times and certainly not in the late twelfth century, when the Anglo-Normans occupied it. I suggest that other forms of settlement co-existed with the raths and that these were open clusters of settlement which have left little if any trace—proto-clachans if you like.

Support for this suggestion comes from the Irish literary evidence. In this, as Duignan, Davies and Evans have all pointed out, there are hints that the unfree members of society lived in clustered settlements distinct from the raths in which the free farmers lived. Sullivan in the nineteenth century had no doubt of this:

> Close to the raths base dependents of the lord erected their wicker houses and formed a village. Some tenants appear to have lived on isolated farms, there being evidence to suggest that free and unfree tenants lived in different areas. Clustered settlements inhabited by freemen holding common land organised politically in partnership and by metal workers or craftsmen also existed.

Perhaps these open clusters of settlement were those referred to individually as *baile* and translated by the Anglo-Normans as *ton* and *villa*. Having considered place-name and other evidence MacAirt believes that the *baile* had to do with a settlement in which plebeian cultivators lived. Certainly townlands incorporating the element *bally-* are more common in east than in west Down; raths and *bally-* townlands together give a more complete picture of settlement corresponding more closely with that suggested by church activity and the later Anglo-Norman settlements in the eastern part of the county.

Scarcity of documentary evidence for the centuries between the collapse of Anglo-Norman power in the mid-fourteenth century and the Plantation by English and Scottish settlers in the early seventeenth century causes a serious gap in our knowledge of the history of clachans at this period. The persistence of place-names containing those elements already discussed and the translation of one form into another in documents of this period suggest that clustered settlements still existed. Similar deductions are surely to be drawn from the the distinction in sixteenth- and seventeenth-century documents between town and townland, or between hamlet and town (= townland). With this lack of documentary evidence it seems likely that the gap in our knowledge of the period from 1350 to 1600 can only be filled by archaeological excavation. It is encouraging that from Murphystown, in County Down, the first clachan site to be excavated, finds of pottery, possibly datable to this period, have been recovered.

Lack of knowledge of conditions in immediate pre-Plantation times is particularly unfortunate, for during the seventeenth century it becomes increasingly difficult, in at least the northern part of Ireland, to isolate those elements in the settlement pattern which are native in origin from those which were introduced especially by the Scottish settlers. Before really satisfactory explanations for many of our Irish settlement problems of the seventeenth and eighteenth centuries can be provided we need more detailed local studies of settlement in Scotland in the sixteenth century.

By the end of the seventeenth century small 'villages', obviously clachans, are mentioned in a few descriptions of the county such as Sir Henry Piers' description of Westmeath in 1682. The first estate maps become available from about the same period and these, along with estate rentals, enable the detailed development of individual clachans to be studied. The most important general point which has emerged from such studies is the flexible nature of Irish settlement forms. Single farmsteads became clachans within a few generations as populations increased, only to revert again as population diminished or as schemes of land planning took place. The concomitance of rundale and clachan settlement is generally accepted but in detail even this generalisation tends to break down. Clachans tended to outlive the disappearance of the rundale with which they had been associated. Less commonly perhaps, clachans were built even in areas from which rundale had disappeared half a century or more before the settlements were established. The plans and even the sites of individual clachans have changed during the last century and a half. Generally, dispersed farmsteads have now replaced the clachan over much of the country.

While many problems in the history of Irish settlement still remain unsolved, archaeological evidence is likely to play an important role in elucidating problems not only of Dark Age but of Mediaeval and Plantation settlement. It remains as the only source for proving continuity of settlement forms from earlier times and substantiating the view that the clachan is a settlement form of great antiquity—a part indeed of the cultural heritage of all Atlantic Europe.

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WALES

By G. R. J. Jones

The systematic study of rural settlement forms began in the late nineteenth century when the theory of a single succession of cultures was current. This theory, reinforced by the uncritical transference of Darwin's findings in biology to

human culture, supposed that all advanced societies had passed through the successive stages of hunting, pastoralism and cultivation, hunting or pastoral communities being regarded as instances of arrested development in the process of unilinear evolution. The inadequacy of this three-stage theory has long been recognised and it is no longer accepted that pastoralism inevitably preceded cultivation (1). Nevertheless, the original bias imparted by this thesis to the study of settlements in pastoral areas has been retained. The purpose of this paper is to survey in one such area the history of rural settlements without presupposing a preliminary stage of exclusive pastoralism.

The characteristic scattering of farmsteads in the predominantly pastoral setting of modern Wales, far from being an expression of a pastoralism representing an arrested stage of development, would appear to be the end-product of complex processes of change in settlement forms. In those Welsh territories which remained independent until the English Conquest in 1283 there were, in the Middle Ages, two distinct settlement forms: on the one hand, small hamlets usually inhabited by communities of bondmen, and, on the other, dispersed homesteads occupied by the members of agnatic kindreds, of whom the majority were free (2).

Every free kindred or 'clan' occupied a *gwely* or *resting-place*—a permanent stake of arable land, which entitled the clan members to grazing rights over extensive common pastures. Each *resting-place* had originated when the eponymous ancestor of the clan, or his immediate predecessor, was permitted to appropriate arable land in a place often referred to as the 'old settlement'. This arable, subject to equal division among male heirs, soon became an open-field *shareland*, and with the growth of population new *sharelands* developed on suitable sites within those territories over which the clan exercised rights of pasture. Sometimes one *resting-place* was confined to one township (rural district), but often more complicated arrangements existed. For example, the members of clan Elidyr in 1315 held 'lands' in the 'old settlement' at Trefydd Bychain and eleven other townships (Fig. 1). By 1300, the average 'clansman' held a homestead, 5–10 acres of arable 'lands' scattered through two or more *sharelands*, and exercised grazing rights calculated in proportion to his arable on unenclosed common pastures. To economize arable land, the scarce factor of production, the dwellings of the clansmen were often built on the outer edges of the *sharelands*, and as the *sharelands* rarely contained more than 100 acres, girdle-patterns of dispersed dwellings frequently developed. Obviously, there were territorial limits to the expansion of each clan and once this stage was reached the continued sub-division of the arable led to the breakdown of *resting-place* tenure. In most areas this had occurred by 1500, and the majority of *sharelands* had been incorporated, along with adjoining portions of the common pastures, into large enclosed, and thus, isolated farms. However, remnants of *sharelands* and girdle-patterns, fossilised at a partial stage of consolidation, are still to be found

The bond communities, whose arable economy had a stronger arable bias than that of the clansmen, held their lands by a primitive egalitarian tenure. Their hamlets usually contained nine adjacent houses and were invariably surrounded by open-field arable. Within every commote (administrative neighbourhood) on the best land available, there was one more important hamlet, *the mayor's settlement*, which contained both the court of the Welsh Prince and his demesne lands. These were cultivated by the labour services not only of the local bondmen but also of those inhabiting the outlying hamlets within the commote. Among the many bond hamlets granted to the Church by the Welsh Princes were *mayors' settlements* containing the bishops' demesne lands and these were cultivated by a similar system (Fig. 2). The decline of the bond population during the later Middle Ages (3) led to the enclosure of the open-fields of most hamlets and many *mayors' settlements* and their consolidation into large isolated farms.

The main problem to be resolved is that of the original relationship between the bond hamlets and the free settlements. The bondmen have long been regarded as the descendants of 'tribal groups' conquered and reduced in social status by later invaders. All previous investigators have postulated a very late survival of 'semi-nomadic tribalism' among these later invaders—the free kindreds—who were

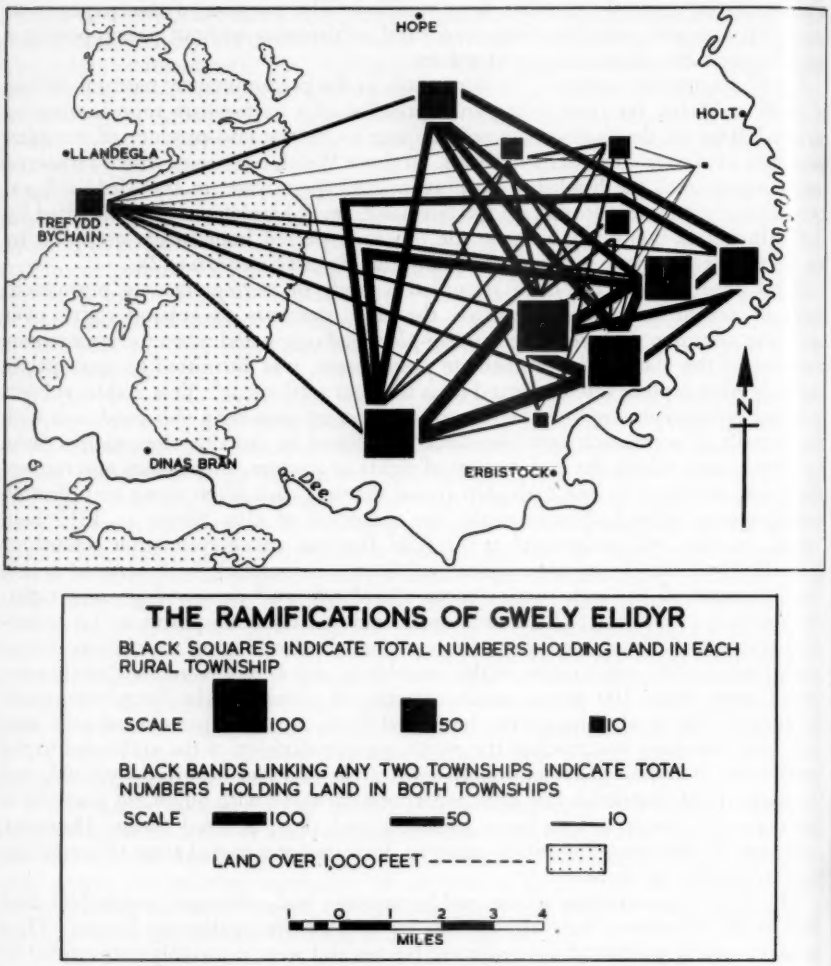

Fig. 1.—The territorial ramifications of a large 'clan' in 1315 A.D.

regarded as having formed the majority of the Welsh population, a numerically and socially superior *caste*, throughout the Dark Ages. When these kindreds settled on permanent *resting-places* after 1100 it was assumed that they did so on land hitherto virgin (4).

The analysis of settlement distributions shows that the 'old settlements' of many free clans had previously been the hamlets of bond communities. For several centuries before 1100, bond hamlets had been granted to individual free-men as well as to the Church. It was not however until after the Norman invasions

that partible inheritance was adopted for some of the lands involved in these donations to freemen, thus leading to the development of *resting-places* and hence girdle-patterns in place of many hamlets. There was, moreover, a parallel process whereby some bond communities were emancipated to form minor 'clans' (5),

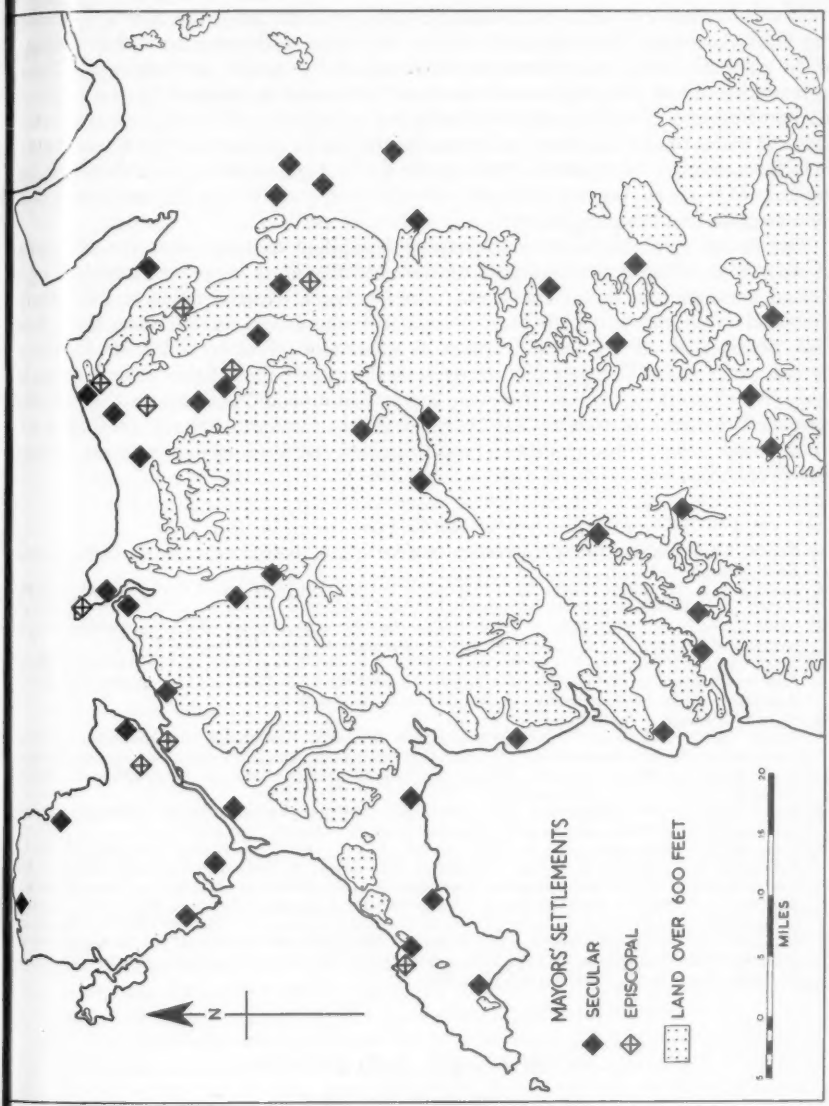

Fig. 2.—The distribution of Mayors' settlements in North Wales during the thirteenth century.

some 'neither purely free nor purely bond', and similar changes in settlement form often ensued (6).

Bond hamlets were therefore more numerous before 1100 than after: indeed, almost every Celtic church appears to have been established in a bond hamlet (7), the only exceptions being occasional lonely hermitages. In addition, for every

mayor's settlement there were numerous dependent bond hamlets. In the Welsh areas surveyed in Domesday Book, there were groups of this kind containing seven to fourteen hamlets, but a much greater antiquity is implied for the bond hamlets by their siting in relation to Iron-Age hill-forts, some of which were reoccupied in the post-Roman period.

So numerous were the bond hamlets, especially in the lowlands of Wales, during the Dark Ages that there was no room for the large, wide-ranging and predominantly pastoral tribes postulated for this period by earlier investigators. Those uplands devoid of permanent settlements were grazed in summer by the herds of all members of society from the Princes to the bondmen, and could have supported pastoral tribes only if the latter had access to the winter pastures of the lowlands (8). It follows that the kindreds of Wales in the Dark Ages were but a small privileged *minority* of freemen, related in blood to the Princes, and, like the Princes, supported by a long-settled bond *majority*.

The focusing of the labour resources of dependent hamlets on to the demesnes of *mayors' settlements* characteristic of Wales in the Dark Ages was matched by a similar arrangement as far afield as Cornwall, Kent, Northumbria and Southern Scotland—districts in which hamlets are still numerous. In all these areas it is now possible to regard these features as a heritage of early Celtic or Romano-British settlement. The new picture presented in this paper of the basic features of early Welsh settlement may therefore have an important bearing on the recently reopened question of Roman-Saxon continuity in Lowland Britain. In this event, in England as in Wales, it should help to bridge the abiding gap between history and prehistory.

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CORNWALL AND DEVON

By W. L. D. Ravenhill

It has long been the fashion to belittle the extent and nature of the settlements occupied by the Celtic peoples in Cornwall and Devon during the hiatus between the going of the Romans and the coming of the English. The Celtic people, whom the Romans found settled and ruling over the south-west of England, have become known to us as the Dumnonii. The numbers and distribution of their Iron Age

dwellings do not suggest a sparsely populated South-West at this time when compared with the rest of Southern England. It is certain that, as yet, more is unknown than known about conditions in Devon and Cornwall during the Roman occupation but what evidence (1) there is suggests some four centuries of peace, a long era in which the settlements of the British peoples may well have prospered. Nevertheless, it has been asserted that a fundamental distinction existed between the British, an upland people who despised and feared the valleys, and the English, a lowland dwelling people who disliked the uplands. Little progress can be made with this concept until British and English dwellings can be recognised in the landscape and their sites subjected to some kind of analysis and classification. The entries in the Domesday Book enable a partial reconstruction to be made of the early English settlements, while archaeological and place-name studies provide examples of Celtic foundations.

The existence in South-West England of a polycyclic landscape with erosion surfaces is largely accepted (2). This is revealed in a systematic staircase morphology of 'rises' and 'treads'. It is, in the last resort, these units of relief, more familiarly known as 'flats' and 'slopes', which offer a variety of habitats to man and which are grouped here under the generic name of sites. Although in detail no two of these units of relief need be exactly alike, the following categories of sites are suggested as appropriate for the discussion of this problem: hill-top, spur, valley-head, valley-slope, valley-floor, coastal.

A site and altitude analysis of nearly one thousand Domesday manors in Devon, Fig. 3, reveals that the English, after some three centuries of occupation, did not live exclusively in lowland farms in the valleys. Sites on spurs and in valley-heads are in the majority, while a gradual increase in the number of manors occurs from sea level to a maximum between the 350 and 400-foot contours. The graph also reveals that before the end of the eleventh century, farming was being practised at heights of nearly 1,200 feet. What prompted the English to occupy such elevated positions on Dartmoor and Exmoor when clearly the lower and more fertile areas were not, then, fully exploited? When some 300 Cornish Domesday manors are examined in like fashion, Fig. 4, similarities with the Devon graphs can be detected, even though a mere century of effective English occupation had passed. It is the valley-head and spur sites which are more numerous. Interest in the dwellings of the Celtic folk prompts one to enquire what were the antecedents of these Domesday manors. Archaeological excavation has proved the occupation of a number of sites (3) by the native Cornish people of the Dark Ages and place-name studies provide further evidence of Celtic settlement. In Cornwall, where the Cornish language persisted in use longer than in Devon, it is possible for Celtic place-names to have been given to settlements at any time up to the recent past. An exception can be made of those places which, anciently, were called after Celtic saints and to whom the local church is dedicated (4). Thus some 200 sites in Cornwall appear rewarding of study and classification as examples of Celtic settlements. Clearly, though the saints may have set up some new foundations, the majority must have lived in or near the contemporary centres of population. No significant differences therefore need be envisaged between ecclesiastical and secular sites.

When the 'physiographic staircase' is set in the sea-girt landscape of Cornwall few dedications would be expected on the exposed hill-tops and ridges. Very much more attractive appear to have been the spurs, those land forms which attained a pre-eminence as the homelands for the Iron Age peoples, and since excavation (5) has proved the re-occupation of a former hill-fort in the Dark Ages, a sudden and entire break with the practices of the past need not be envisaged. The analysis, Fig. 4, further reveals that the era of the Dark Ages in Cornwall was a formative one in the evolution of settlement. It is clear from the number of valley-head sites that an attack on the forests was being made and a valleyward movement under

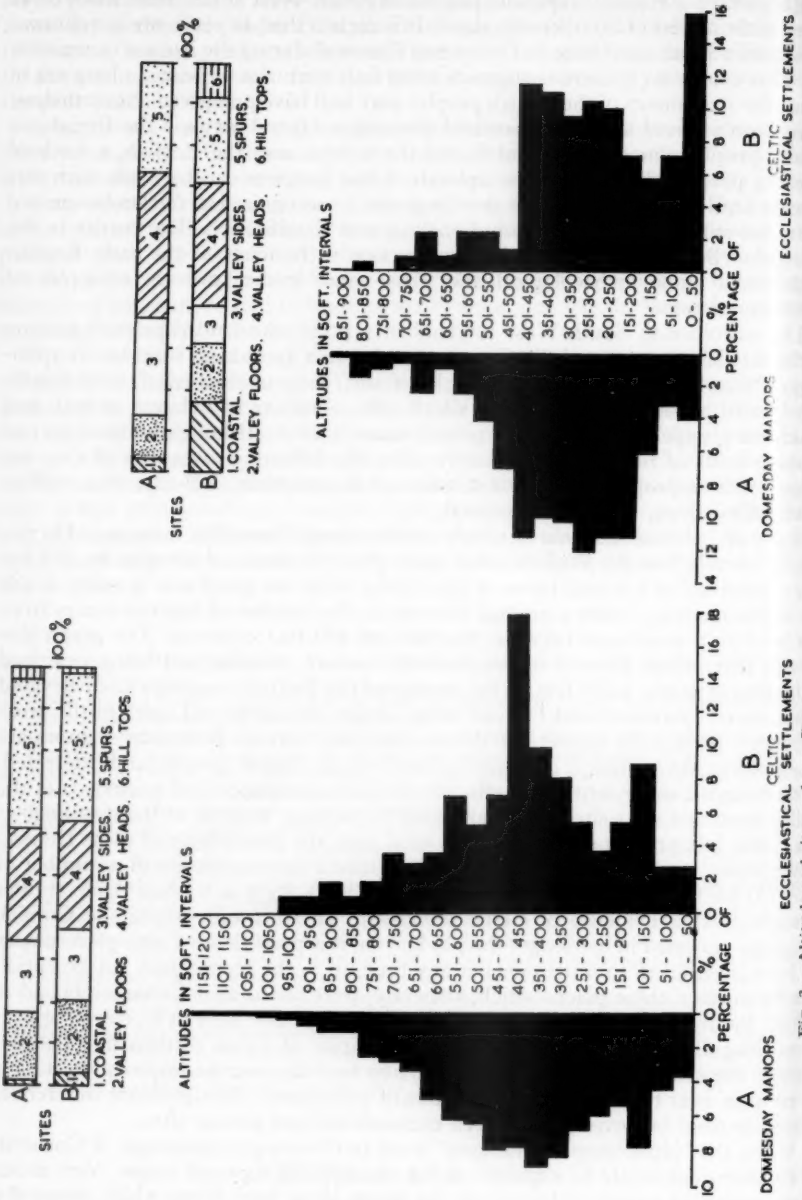

Fig. 3.—Altitude and site analyses, Devon.

Fig. 4.—Altitude and site analyses, Cornwall.

way. The occupation of land on valley-floors was also undertaken at this time and this interesting feature of Celtic settlement merits recognition, as there has been a very strong tendency to credit the English settlers only with this seemingly advanced cultural accomplishment (6). Further evidence that the native Cornish lived in the lowlands is provided by the large number of dedications on the coast

and alongside the many estuaries and tidal creeks which delve deeply into this tapering land mass.

The surviving dedications in Devon are far less numerous than in Cornwall, but owing to the earlier date and nature of its conquest by the Saxons leading to an eclipse of the native tongue, Celtic place-names which appear in early charters provide additional examples of true native British settlements (7). Nevertheless, the number of examples remains small and the Place-Name Society reached the conclusion that 'in the middle of the seventh century . . . no considerable native population remained to complicate the life of the new settlers' (8); an interpretation which has not survived unchallenged (9).

The choice of sites on which to dwell has always been important but never more so than during the Dark Ages in Britain. The conclusion which emerges from the analyses illustrated in Figs. 3 and 4 is that there was either no difference in the habitation sites chosen by the two peoples or that the Saxons took over or settled alongside the Celtic folk. The pre-Conquest charters and the Domesday Book make unmistakably clear the extensive expropriation of Celtic ecclesiastical properties in Cornwall by the Saxons and, later, the Normans. One could hardly expect the secular dwellings not to have suffered a similar fate and what holds good for Cornwall would certainly apply to Devon at an earlier date.

The danger, in turn, of overstating the case for the Celtic settlement must be avoided. It would indeed be rash to claim that the Saxons made no, or even a small *de novo* contribution to the settlement of the two counties by 1086. Even when all the scraps of information have been brought together only a very imperfect picture of the landscape of the time emerges. Clearly, however, the two types of settlement—Celtic and English—are not mutually exclusive. Maps can be drawn to assess the contribution made to the modern settlement pattern by sites known to have been established before the close of the eleventh century; these show the contribution to be substantial. Whether so many relict features in the present landscape are Celtic or English in foundation is a theme of much interest in the study of rural settlement in South-West England.

Fig. 3.—Altitude and site analyses, Devon.

Fig. 4.—Altitude and site analyses, Cornwall.

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THE POTENTIAL CULTURAL VALUE OF THE ASSEMBLY OF CORRESPONDING SOCIETIES[1]

ADDRESS BY THE RT. HON. LORD BOYD ORR, D.S.O., M.C., F.R.S.

PRESIDENT OF SECTION X

In this address I am going to suggest that in the present critical phase of the evolution of human society Section X might well become the most important and by far the most popular Section of the British Association. In support of this suggestion I will ask you to consider:

I. The change in the facilities for scientific education and research since 1831, when the Association was established.
II. The achievement of modern science.
III. The problem created by science.
IV. Section X as a suitable forum for the discussion of these problems upon which the survival of our civilisation and, possibly, of the human race depends.

I. The Change in the Facilities for Scientific Education and Research since 1831

In the early part of the nineteenth century, science was not much esteemed by the ruling class in England. It was considered rather an inferior form of intellectual activity and indeed a possible danger to the authority of the Church and State. There was reason for this fear. In the latter half of the eighteenth century, France was the chief centre in the world for the advance of science and subversive ideas there about the rights of the common man, and suggestions like those of the Marquis de Condorcet that the new knowledge should be applied to the elimination of the intolerable evils of poverty, hunger and disease, had brought about the revolution of 1789 with the downfall of the power of the Church and of the hereditary aristocracy.

The Rev. Mr. Malthus foresaw the danger of technology. He said that with the 'Iron Machine' there would be less need for human labour, with an increasing population needing to be supported in idleness and, therefore, a burden to the country and in this there was a danger of socialism. That was not an intellectual atmosphere in which science with freedom of thought could flourish. Indeed, freedom of thought was restricted in the only two Universities in England. In these preserves of the wealthy ruling class, admission was barred to those who did not accept or pretend to accept the infallibility of the doctrine of the State Church and its authority in spiritual and intellectual spheres. In the Universities, the main subjects of education were the mechanics of two dead languages and philosophy, derived largely from civilisations which, having failed through lack of wisdom to adjust their societies to new conditions, had perished.

It is worth recalling this reluctance to face the implication of the advance of science a hundred and fifty years ago, because in our own day there is something like the same reluctance on the part of many leading politicians in all countries to face up to the political and economic changes which modern science has made inevitable, but which conflict with cherished preconceived ideas or seem to threaten national or class interests.

[1] Address delivered to the Assembly of Corresponding Societies on Thursday, August 28, 1958, at the Glasgow Meeting of the British Association.

In spite of the reluctance of those in authority to promote science, the freedom of thought and inquiry into natural phenomena which had arisen in Italy after the Renaissance and flourished in France, reached these islands in the seventeenth century. In 1645 there were in London monthly meetings of 'diverse worthy persons inquisitive into natural philosophy'. This developed into the Royal Society of London. In 1799 the Royal Institution was established, providing research facilities for Humphrey Davy, Faraday and others. There also arose a number of local philosophical societies and technical institutes, many of them not unlike the societies of this Section. Of these the most important was the Lunar Society of Birmingham, where scientists and business men met to consider results of experiments. Connected with this society were some men from Scottish Universities, to which admission was free to anyone able to pay the modest fees and where there was complete freedom of thought—which enabled scientists and technicians like Black, Cullen and Watt to make great advances and men like Hume and Adam Smith, who reasoned from ascertained facts instead of the dreary futilities of arguments based on assumed but unproved first principles, to become apostles of freedom.

All these societies, though praiseworthy pioneer efforts, were rather local, with limited means of developing science. The need for a bigger move led Sir David Brewster with a few other enlightened men to form the British Association for the Advancement of Science. It popularised science and, by providing a forum where research workers and others interested could meet to discuss recent developments and exchange views on further suggested investigations, helped to put science on a national basis.

After 1831 there was a gradual advance in science with a great acceleration in the last few decades. Now there are government research organisations for industry, agriculture, medicine and war, with fourteen new Universities whose most important subjects are pure and applied science and the two older Universities taking a lead in research. This country is now spending about £300 million a year on research through the Defence Forces, industries, government organisations, Universities and other institutions. What a contrast to pre-1831 days when there were few facilities for scientific research and advance depended almost entirely on the efforts of enlightened private individuals.

Achievements of Modern Science

With the increased facilities for research, science has advanced more in the last fifty years than in the preceding two thousand. It has produced the hydrogen bomb, biological and other instruments of death so powerful that it is physically possible to kill all human beings and all other higher forms of animal life on our planet. One would have thought that was enough to be going on with. But science marches on. There is more money being spent on devising still more deadly weapons and means of defence against them than in any other field of research.

Applied to industry, science has increased the output per man to such an extent that in spite of the destruction of two world wars and—since then—the devotion of about a third of the National revenue to preparation for another war, the standard of living in this and other industrialised countries is much higher than in 1914. We are evidently only at the beginning of this plethora of wealth. For example, Walter Reuther has predicted that with automation and other advances it will soon be possible for two hundred thousand workers to turn out as many motor cars as are now being produced by the nearly million men now employed in the automobile industry in the United States. One electronic computer can replace hundreds of clerks.

An equally rapid advance has been made in biological science. In agriculture the Department of Agriculture in the United States estimates that in 1911 one worker

produced sufficient food and cotton and wool for clothing for seven people. Today, he produces sufficient for twenty-one people. The increased output per man is probably even greater in this country where agriculture is now as mechanised as in America and the average yield per acre is higher.

In medicine, the expectation of life at birth has increased in this and other industrialised countries by twenty years since 1900 and it is confidently predicted that with the advance in gerontology and other branches of medicine, centenarians will be as common by the end of this century as octogenarians are today.

No less wonderful is the conquest of space. The jet plane and wireless have made the world smaller in terms of transport and communication than England ever was fifty years ago. Jules Verne wrote a fiction thriller *Round the World in Eighty Days*. One can now go round the world in eighty hours. Travellers can dine in Karachi and breakfast next morning in London. Within a few years we will have nuclear-powered jet planes which will not need to land for re-fuelling and will be able to circle the earth in less than twenty-four hours. Equally astounding is the speed of communication: the voice of a man speaking into a microphone can be heard as clearly thousands of miles away as in the room in which he is speaking.

Thus the advancement of science for which this Association was established has been magnificently achieved and has given man more powers than the ancients ascribed to their Gods. The thunderbolt of Jove was a pipsqueak compared with the hydrogen bomb; Mercury, the messenger of the Gods with wings on his heels, was a non-starter compared with the radio; Hygeia, the Goddess of health, an ignorant charlatan compared with modern medicine.

Problems Raised by the New Conditions Created by Modern Science

The most important new condition created by science is the enormous increase in the power of weapons of war. After the last world war, at the end of which the atomic bomb was tried out on Hiroshima, President Eisenhower said that if there were another war with these bombs civilisation as we know it could not endure. Now we have the hydrogen bomb, more than a thousand times as powerful. It could cause total death and destruction at a distance of fifteen miles and partial destruction at a distance of thirty miles. One such bomb on London and London would be a thing of the past. There is little wonder that there is a popular movement to ban the use of this bomb in war.

But even if it were possible to ban the bomb, we would still have tactical atomic weapons which are more than a hundred times as deadly as the biggest block-busters of the last war. The only difference would be that it might take a few weeks instead of a few days or hours to bring about wholesale death and destruction in the main battle area—which would likely be Europe. The only hope of survival is the banning of war itself, by a world Government which could bring about a gradual and equal disarmament of national armies and replace them with a powerful United Nations Police Force able to keep the peace. As Sir Winston Churchill said, without some sort of world government, there is no hope for the future. Science has made war obsolete, and increasing the supply of bombs and other lethal weapons—to be able to 'negotiate from strength' with another nation armed with modern weapons—is futile, because no nation can apply its military power without committing suicide. How to change from the age-long use of war as the last instrument of diplomacy to a new era of world peace, in which differences between nations will be settled by reason and goodwill, is the biggest problem created by modern science.

An economic and social problem has been created by the great increase in the capacity for production with the rapidly increasing output per man-hour. Modern

technology has lifted the burden of labour from man's shoulders and changed an era of inevitable poverty for the majority of mankind into one of potential abundance for all the people in the world. How can the economic system be adjusted to carry the great wealth of goods which modern technology can produce, without war to destroy wealth or periodic 'slumps' with large-scale unemployment?

But it is only the fully industrialised countries which have the problem of the dispersal and consumption of rapidly increasing amounts of all kinds of goods. The undeveloped countries have a difficulty in increasing production to keep pace with increasing population. The poverty of two-thirds of the world's population, most of whom were until recently subject races, is the fundamental cause of the nationalism in these countries and of the enmity against the white man, whose exploitation is blamed for their poverty. How can the widening gap between the increasing wealth of the Western industrialised countries and the poverty of the once subject nations be narrowed? Can we get all governments to co-operate in an international economic and financial system which would enable the poor countries to develop their natural resources quickly with a rapid rise in their standard of living and which, by massive investments by the wealthy countries, for the development of the poor countries, on business lines, would provide a rapidly expanding world economy to keep pace with the rapidly increasing capacity for production by a great expansion of world trade? Or must we wait till they become industrialised mainly by their own efforts, when, with their larger populations, they will become more powerful than the European nations which once conquered and ruled them?

Increase of wealth, with a rise in the standard of living and a shorter working day, has raised a social problem. The United States is the wealthiest country in the world. Sweden and this country have advanced social services with more money and more leisure for young people who, fifty years ago, would have been working an eight- or nine-hour day. This increased leisure has been accompanied by increased juvenile delinquency. These young people are not fitted either intellectually or ethically to enjoy their leisure. Can our educational system be adjusted to make young people responsible citizens? Or is human nature such that the only remedy for this increase of crime among young people is some sort of a national service which would discipline them by two or three years manual labour for all, including the wealthy, from say 14 or 15 years to 17 or 18—labour which might help to condition them to the new age of wealth and leisure?

These are a few examples of the many problems which modern science has created. If mankind has the intelligence and the moral attributes needed to solve them, the troubles of our time are but the birth pangs of a wonderful new era. Some people doubt whether these problems can be solved. Henry Adam in one of his letters recently published said:

> Man has mounted science and it has run away with him. Some day science may have the existence of mankind in its power and the human race commit suicide by blowing up the world.

That prophecy, so far as the power of science is concerned, has been fulfilled. Bertrand Russell believes that there is only a fifty-fifty chance of any human beings being alive on this planet by the end of the present century. Sir Charles Darwin believes that even if war be avoided other problems are insoluble, and that we are now living in the twilight of the golden age of our society.

Such is the dangerous position into which the advance of science has driven human society.

The New Importance of The Assembly of Corresponding Societies

This Association was formed for the advancement of science. What is needed today is a world-wide association for the retardation of science and for the preservation

and increase of what little culture we have to enable us to deal with the forces science has already let loose. (I am using the word culture as meaning knowledge, wisdom and goodwill.) The necessary adjustments cannot be brought about in a democratic country unless the general public are informed of the need for them. The government cannot lead where the people are not prepared to follow. Indeed every great reform has been brought about by the pressure of public opinion.

In the early days of the Association, one of its most valuable functions was to provide a meeting place for those interested in each branch of science. Today each branch has its own periodic meetings and its own journal, and the Association has become more and more devoted to enlightening the public on the advance of science and its impact on society. The excellent addresses of the President of the Association and Presidents of its different Sections make a valuable contribution to the education of the public.

I venture to suggest that this should now be recognised as the main function of the Association. In addition to meeting for the discussions of their own subjects, several Sections might unite for the discussion of some problems of common interest. For example, some of the biological Sections might join in a discussion of the present explosion of world population, which will double it in forty years or less; and consider the changes needed to accommodate twice as many people, and more than twice as many motor cars and aeroplanes, and how long, if the present accelerating rate continues, the earth will be able to support its human population. Some of the physical Sections might consider problems like the possible exhaustion of non-renewable natural resources, or the possible expansion of sources of energy on which material advances depend, or the rate of 'fall out' from tests of nuclear weapons and its effect on health. Such discussions would be of great interest to the general public. They would be of interest even to scientists engaged in research on narrow, specific problems, by giving them a wider outlook on the broad general advance of science, of which their own may be only a narrow sector.

In this natural evolution of the function of the Association, Section X would have a new significance. Its 170 societies are composed of the more intelligent part of the general public. Their members, interested in science and drawn from many different fields in the work-a-day world, with a wider knowledge of world affairs than the highly specialised research worker, may be better able to assess the importance of new discoveries and also of how the general public react to them. The Section could discuss the broader aspect of some of the problems considered in joint sessions of allied Sections and so give them a wider publicity in terms that the common people could understand. They could also discuss the really great issues such as peace with progress, or war with annihilation; or whether the democratic societies will be forced to become more and more totalitarian to be able to cope with the advantages of the already totalitarian governments and, if so, whether the lights of liberty which illuminated our development in the nineteenth century will be dimmed and gradually extinguished.

Such are the great issues which confront us today. The common sense of the common people, which can find expression in Section X, is a better guide for the future than the view of experts in either science or politics. In my opinion, the Council of the Association might consider making Section X the main means of getting the public to understand the implications of modern science, and so help to create the new thinking of the general public needed for the new era on which we have entered.

THE APPLICATIONS OF CRYSTALLOGRAPHY TO CHEMISTRY

SECTION B (Chemistry) devoted the morning of Friday, August 29, 1958, at the Glasgow Meeting of the British Association to a discussion of the applications of crystallography to chemistry. Prof. J. Monteath Robertson, F.R.S., Gardiner Professor of Chemistry at the University of Glasgow, introduced the session with a paper on 'The measurement of molecules by X-rays'. He was followed by P. Pauling of the Dept. of Chemistry, University College, London, whose paper was entitled 'A rebirth of inorganic crystallography'. The final invited contribution came from H. M. Powell, F.R.S., Reader in Chemical Crystallography in the University of Oxford, who considered 'How molecules fit together'.

The paper by Professor Robertson is printed in full below.

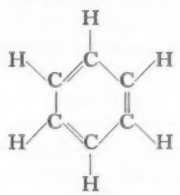
MEASUREMENT OF MOLECULES BY X-RAYS

By Prof. J. Monteath Robertson, F.R.S.

One of the major tasks of chemistry is to determine the arrangement in space of the atoms which form the molecules of chemical compounds. There is no need for me to remind this Section of the British Association how successful these efforts have been. During the last 100 years precise structural formulae have been assigned to many hundreds of thousands of different chemical substances, formulae, which show the correct relative position in space of all the atoms in the molecule. This knowledge has been achieved by painstaking analysis and synthesis and a process of gradual building up from simple to ever more complex materials.

During the last forty years or so a new and exceedingly powerful method of determining atomic arrangements has been developed, the method of X-ray crystallography. This new method is now rapidly extending our knowledge of chemical structure, and in this paper I shall deal with applications in the field of organic chemistry.

There is no time for me to describe methods in any detail, and I must confine myself to certain outstanding results that have been attained. Yet I would like to point out how entirely different in approach are the chemical method and the X-ray method. The aim is the same, to discover the arrangement of atoms in space. The chemical method proceeds from an analysis of composition and a study of the properties of compounds, to a correlation of these with simple conceptions of valency. It was Archibald Scott Couper of Kirkintilloch (a town not far from here) who first represented units of valency by drawing lines between the chemical symbols; and Kekulé in 1865 first gave us the formula for benzene, C_6H_6.



In contrast, the X-ray method proceeds by direct measurement and calculation from the diffraction pattern. The picture of the benzene molecule, obtained in this

way by Professor E. G. Cox (1) (Fig. 1), shows a time average of the distribution of electrons, and the atoms stand out as peaks on the contoured diagram. This is a section evaluated in the mean plane of the molecule and each contour line represents a density increment of 0·25 electrons per Å^3. The main cause of the blurring of the atoms that we observe in this diagram is the fairly large amplitude of thermal movement which they possess in the crystal (temp. −3°C), mainly an oscillation about the sixfold axis (amplitude 7–9°).

Similar sections of the naphthalene and anthracene molecules are shown in Fig. 2, based on a very complete evaluation of the X-ray intensity data (2). These

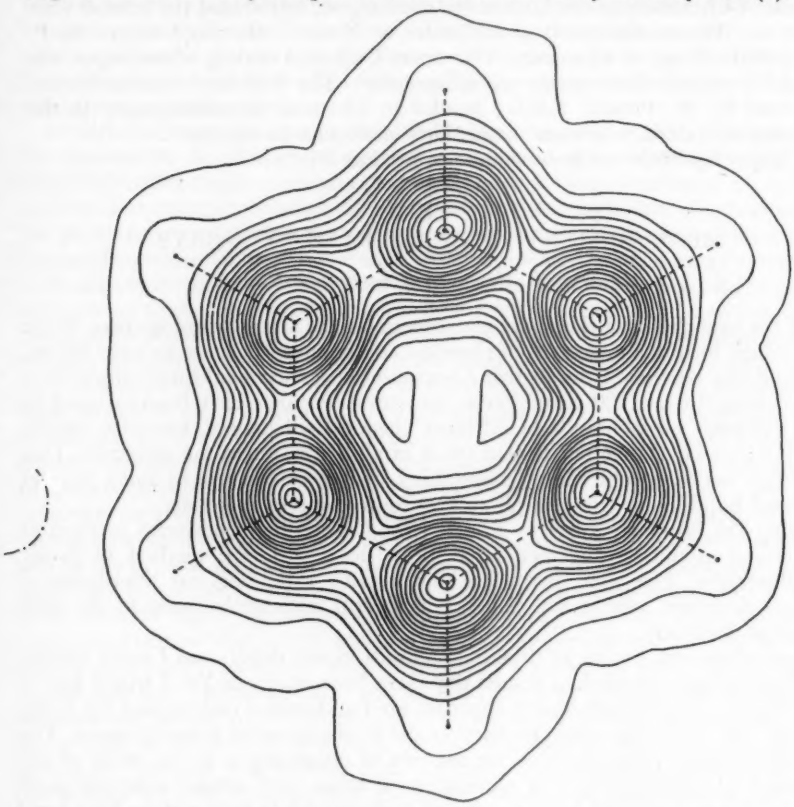


Fig. 1.—Benzene. Electron density section in the plane of the molecule (E. G. Cox).

crystals have higher melting points than benzene and the thermal movements of the atoms, although still large, are less than in benzene. The definition of the atoms is now so good that the bond lengths can be estimated to within a few thousandths of an Å.

Further elaborate refinements have recently been carried out on these molecules by Dr. D. W. J. Cruickshank (3) to try and obtain evidence regarding the distribution of the electrons that form the chemical bonds between the atoms. Briefly, the method consists of calculating the theoretical distribution of electrons in an isolated or non-bonded carbon atom. The thermal movement, which smears out the electron distribution, is then carefully calculated from these experimental maps, or from the X-ray intensities. The theoretical atoms, each with its proper

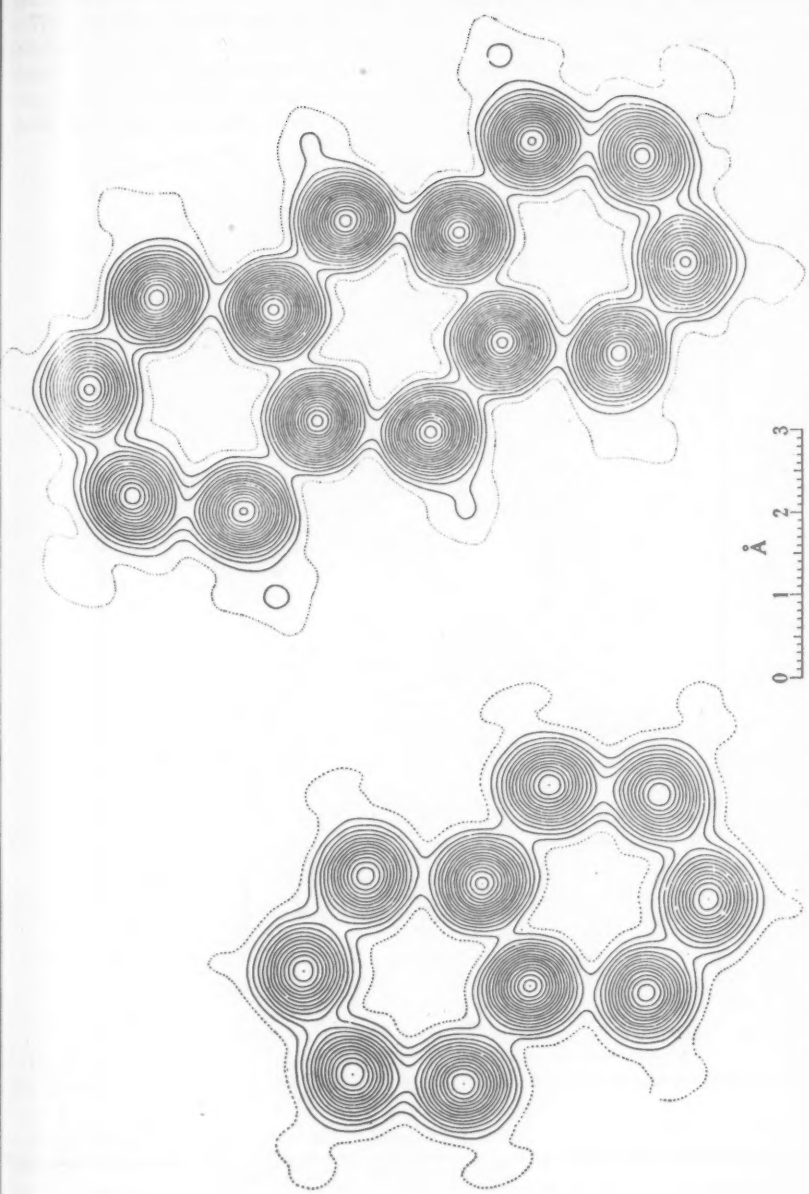


Fig. 2.—Electron density sections through the central planes of the naphthalene and anthracene molecules. Contour interval, 0·5 electrons per Å^3.

thermal movement but non-bonded, are then subtracted away from the experimentally observed electron distributions. Any residual electron density may then be attributed to the effect of the chemical bonds.

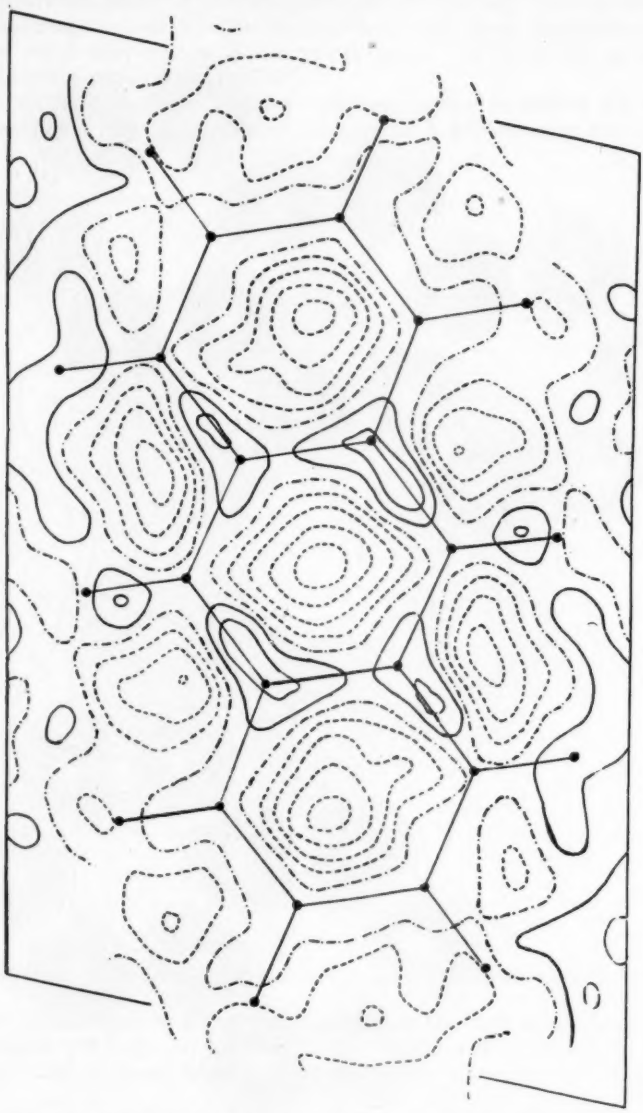


Fig. 3.—Anthracene difference map in the central plane. Anisotropic carbons and isotropic hydrogens subtracted (D. W. J. Cruickshank).

The result for anthracene is shown in Fig. 3. At this limit of refinement the accuracy of the observations (the measured intensities) is not sufficient to yield really conclusive results. But we see evidence of a fairly definite ridge of residual density running round the aromatic rings and along the directions of the chemical

bonds. These results are in agreement with chemical theory for aromatic systems, but more accuracy is required before final conclusions can be drawn.

Work of this kind is not always direct and there are many tedious calculations involved. It is often necessary to borrow all we know from the chemically established structure in the early stages of the investigation. The final results, however, obtained by an iterative process, are independent of any initial chemical assumptions. In favourable cases it is sometimes possible to make a very direct analysis,

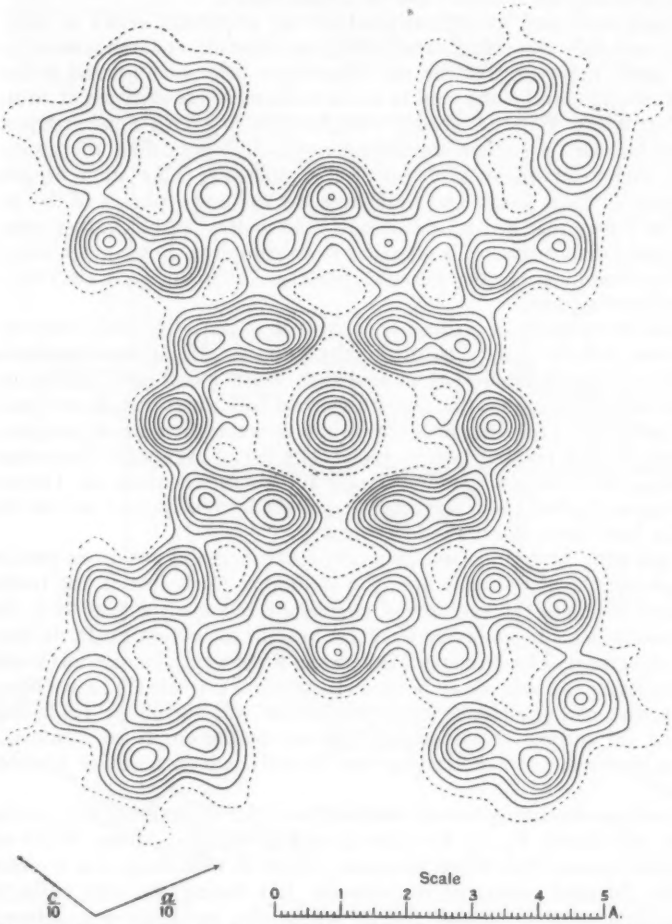


Fig. 4.—Electron density projection for nickel phthalocyanine. Contour scale, one electron per Å^2.

without knowing anything of the chemical structure in advance. This is most important when we are dealing with new, chemically unknown or incompletely known, structures, where the object of the work is not so much extreme accuracy as just to locate the atoms in order to discover the structural formula. A good example was obtained in the 1930's from the phthalocyanine compounds (4). Here (Fig. 4) there is a central metal atom of fairly high scattering power for X-rays. It can be removed at will, and the effect on the diffraction pattern noted. In this way, by a relatively simple calculation, the relative phase relationship of all the

X-ray reflections, or diffractions, can be determined. The diagram in Fig. 4 can then be immediately constructed by straight-forward summation of a Fourier series whose coefficients are obtained from the measured intensities.

This is not a section, but a projection of a larger planar molecule, with four benzene rings at the corners. All the atoms are clearly resolved and it is even possible to distinguish carbon from nitrogen atoms, due to the slightly higher peaks and greater density of the latter. These results fully confirm the chemical structure proposed by Linstead and his collaborators.

This compound and its derivatives form an important series of dyestuffs or pigments, and they were discovered rather accidentally at Grangemouth in 1928. I like to think, however, that the real importance of this compound is that it first and most clearly showed the way to make a direct X-ray analysis of an unknown chemical structure. What we need is a single atom, or even a small group of atoms, somewhat heavier (or rather containing more electrons) than the atoms of the unknown carbon-hydrogen skeleton of the molecule. This atom or group acts as a marker, or focal point, and influences the unknown phases of the X-ray reflections in a way that can be calculated. The general case is rather complicated and the phase determination is often far from complete. But enough can often be achieved to commence some iterative process which finally leads to a solution complete in every detail.

With the compounds of organic chemistry it is generally fairly easy to insert a marker atom without unduly disturbing the structure. Halogen atoms may often be attached, or if the compound is an acid then heavy metal salts may be prepared. I think it is true to say that this general method has been utilised, in some form or another, in the great majority of X-ray structure determinations of complex organic compounds during the last twenty years. The list of successful determinations is now so large that it would be tedious to try and enumerate them all. The structures of many natural products in the terpene and alkaloid fields, and several important antibiotics have been determined in this way.

To begin with the results have generally confirmed and put on an exact metrical scale what the chemist already knew, in outline at least. But as the technique of the subject advances the solution of chemically unknown structures is becoming more feasible. Already some notable contributions have been made. In the terpene field the structures of longifolene (Moffett and Rogers (5)), lanostenol (Fridrichsons and Mathieson (6)), and oleanolic acid (Rahim and Carlisle (7)) have been solved. The structure of the alkaloid isocryptopleurine was solved by Fridrichsons and Mathieson (8) without any chemical data except the empirical formula, and the tropolone derivative, nootkatin (9), was recently solved in these laboratories in Glasgow.

Much the most striking recent result in this field, however, is the solution of the structure of vitamin B_{12} by Dorothy Crowfoot Hodgkin, John White and their many collaborators (10). When this work began in 1948 there was no information about the chemical nature of the vitamin. But during the next eight years the chemical structure of various groups within the molecule was determined. A nucleotide-like group consisting of a benziminazole ribose phosphate, a propanolamine residue and various amide groups were discovered. There was also a cyanide group and, most important, a large fragment containing cobalt which it was suspected might be a porphyrin-like nucleus. There was, however, no very direct chemical evidence as to how all these groups might be linked together.

The presence of the cobalt containing fragment and the possibility of a nearly planar porphyrin group (the crystals are strongly pleochroic) stimulated the X-ray work. If a structure is not too complex the presence of a single atom like cobalt, favourably situated, may sometimes, as we have seen, lead to a very complete structure determination. But vitamin B_{12} is vastly more complex than the com-

pounds we have been considering. The cell dimensions of the air-dried crystals are about 24 × 21 × 16 Å. (Space group $P2_12_12_1$ with 4 molecules.) The positions of the cobalt atoms were not difficult to find. An early model of the structure showing the general orientation of the possible planar group (and the C—N group) is shown in Fig. 5.

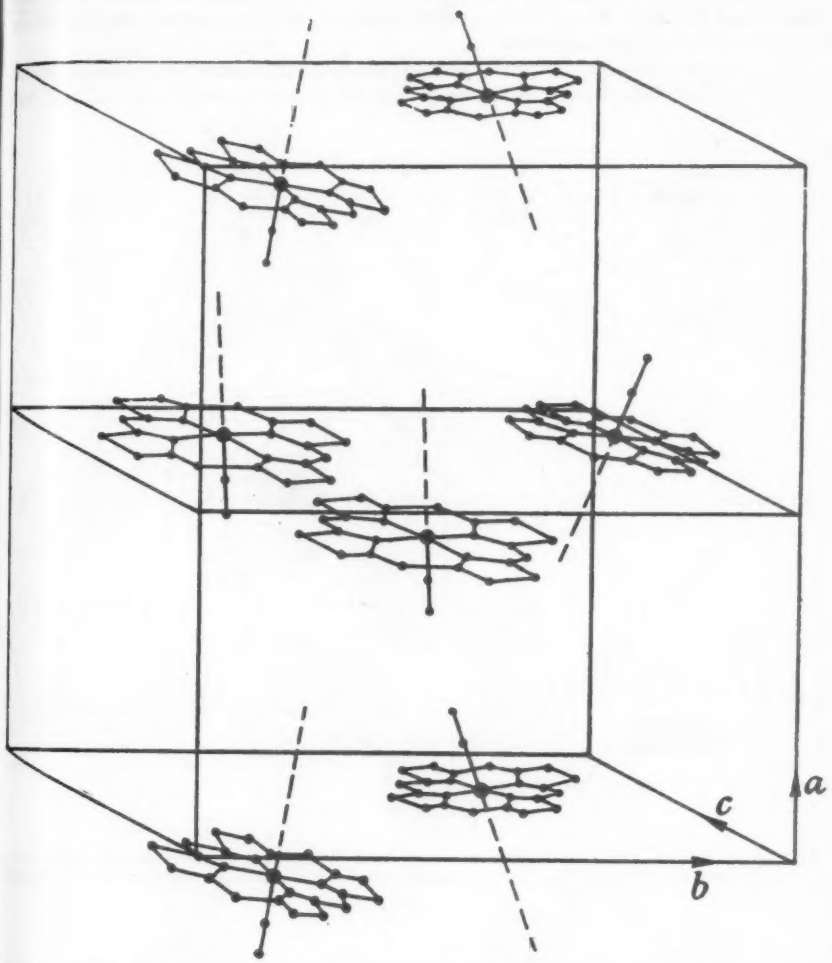


Fig. 5.—An early model (1951) of the vitamin B_{12} structure, showing the general orientation of a possible 'planar' group (D. C. Hodgkin *et al.*).

But with phases based on the cobalt contribution the density maps are very blurred and confused. Fig. 6 shows a rather arbitrary section of an early calculation from the air-dried crystal, in which a possible porphyrin ring has been sketched in. Some other parts of the molecule are also visible but they are too difficult to interpret.

At this stage help was obtained from a study of the various other compounds that had been prepared by the chemists. In addition to the wet and air-dried

vitamin, two other compounds proved to be most useful. These were the selenocyanate derivative, $B_{12}SeCN$, with a second heavy atom, and most important of all, a hexacarboxylic acid obtained by degradation (alkaline hydrolysis), which contained the porphyrin nucleus and its side chains. This crystalline fragment, obtained by Todd and his co-workers, was much less complex than the full vitamin ($C_{46}H_{58}O_{13}N_6CoCl$ instead of $C_{63}H_{88}O_{14}N_{14}PCo$, but these formulae were not established till later). Even this fragment, however, still represented an excessively complex structure determination.

The general method of attack was now to pursue all these structure determinations simultaneously. When some atoms or groups of atoms became fairly definite, and

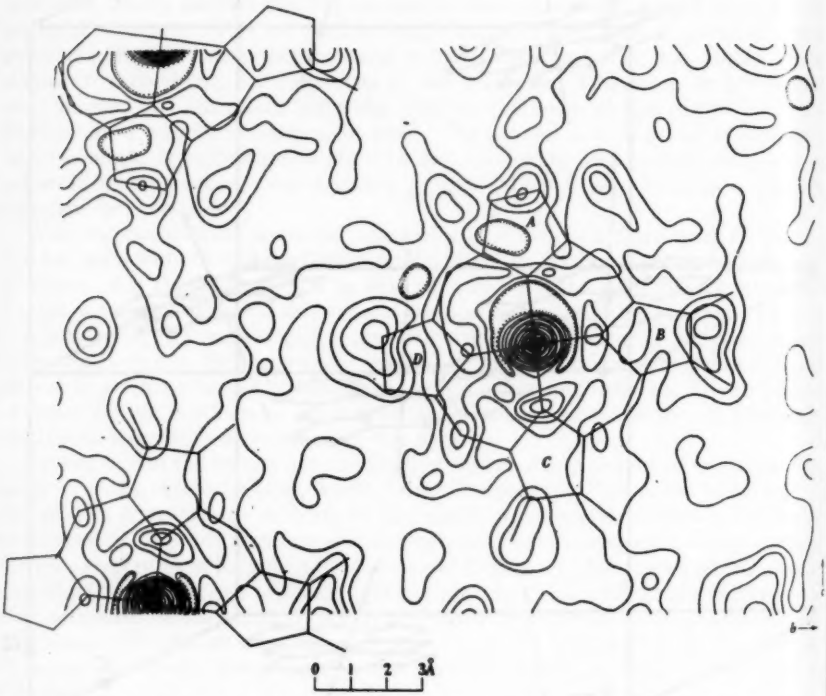


Fig. 6.—A section at $x = 0$ through the first three-dimensional electron density distribution calculated for air-dried B_{12}. A possible porphyrin ring has been sketched in (D. C. Hodgkin *et al.*).

were confirmed by their appearance in the maps obtained from the other derivatives, then those atoms were inserted in the phasing calculations in gradually increasing numbers, which resulted in diagrams of increasing clarity and definition. Fig. 7, for example, shows one fairly advanced stage on the dry vitamin, which was studied intensively by White at Princeton. It shows the side-chain structure of the porphyrin part with many of the atoms clearly defined, but some of which are still wrong. By this time the structure of the nucleus itself had been fairly well cleared up, and it contained one unusual and unexpected feature which was at first difficult to accept. This was the direct linking of two of the five-membered rings (A and D) without an intermediate bridging atom, and with a methyl group attached directly to one of the tertiary carbon atoms.

Fig. 7.-

Fig. 8.—

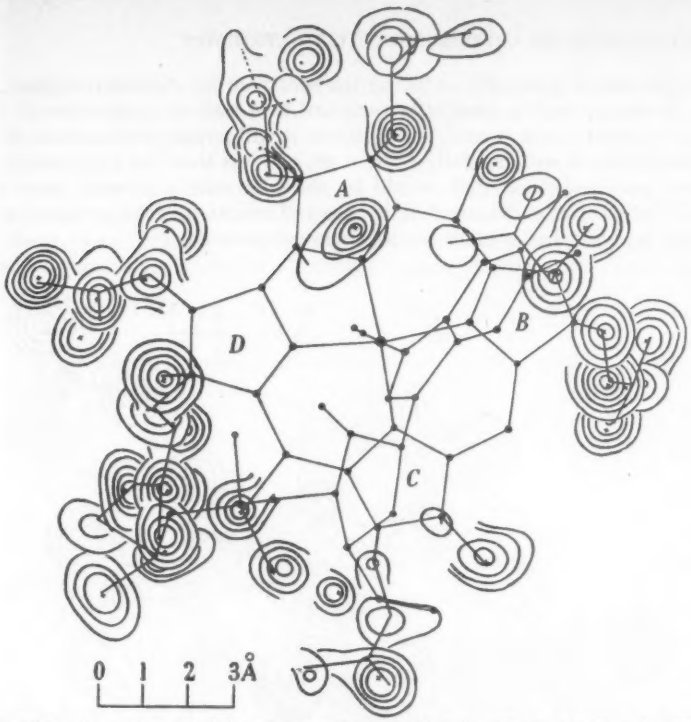


Fig. 7.—A fairly advanced stage of the structure determination for dry B_{12} showing the side-chain structure (D. C. Hodgkin *et al.*).

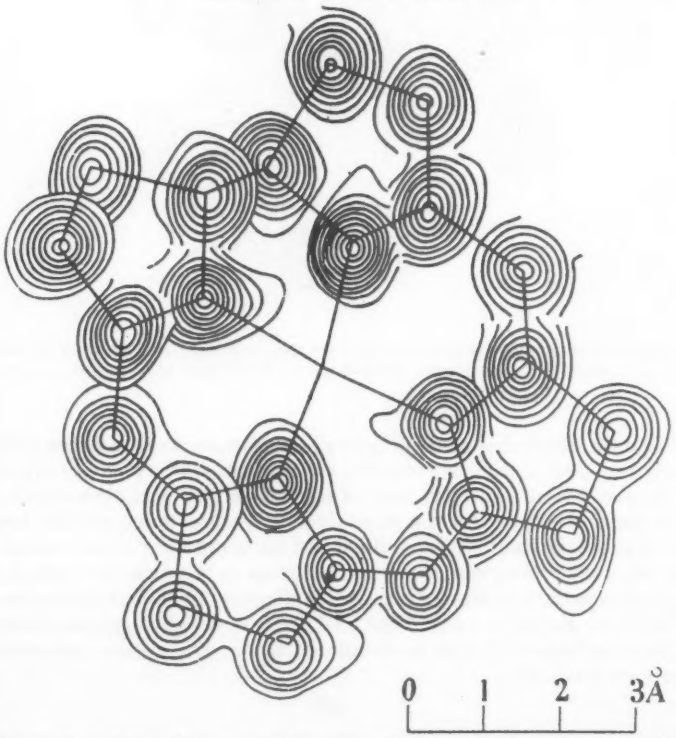


Fig. 8.—A very clear picture of the porphyrin nucleus taken from the hexacarboxylic acid. Contour intervals, 1 electron per Å^3 (D. C. Hodgkin *et al.*).

The process of gradually deducing the structure by successive approximations is not, however, such a straightforward and easy task as it may sound. If a false atom is inserted in the phasing calculations it will appear in the place where it is put. But if false it will generally cause a peak of less than the expected height and be more poorly defined than would be the case with a genuine atom correctly placed. The work requires much judgment and intuition, and a continual process of checking against what is plausible on chemical grounds.

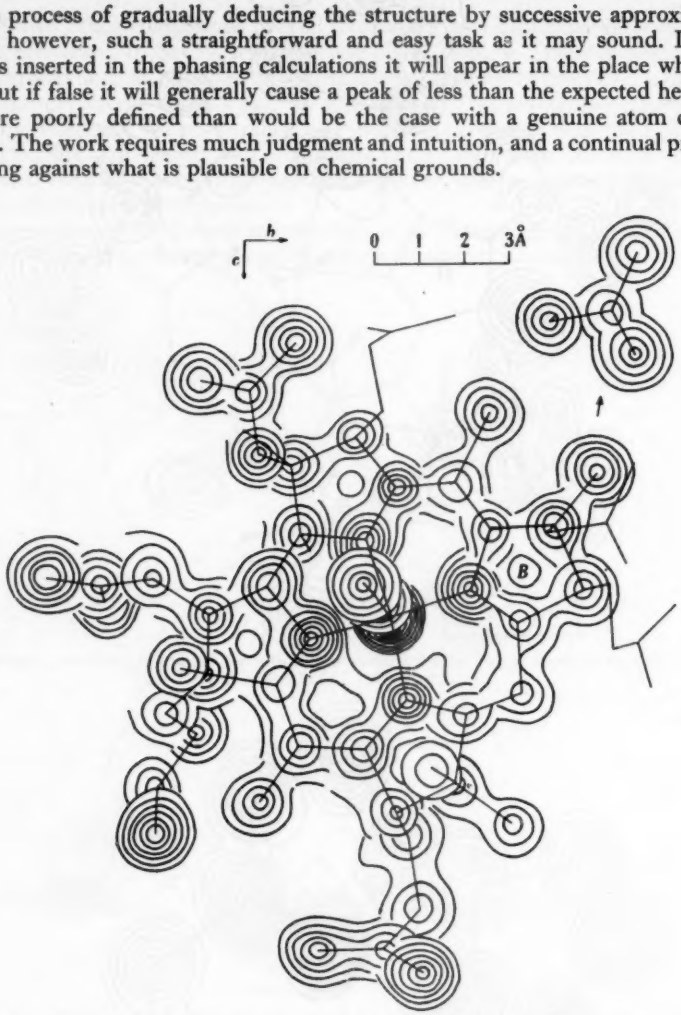


Fig. 9.—A portion of the electron distribution in the wet vitamin crystal, showing the nucleus with most of its side chains attached (D. C. Hodgkin *et al.*).

Another difficulty in this work, of course, is the tremendous amount of numerical calculation required. Each stage involves the evaluation of a triple Fourier series of several thousand terms at many tens of thousands of points throughout the unit cell. It is essentially a job for the large electronic computers; and the later stages of the work owed much to Dr. Trueblood and the computer SWAC at Los Angeles.

In the latest work the positions of all the atoms in the molecule and of about 12 out of an estimated 24 molecules of water in the wet crystal have been ascertained. In the following diagrams some of the final electron density maps are shown.

The clear definition of this multitude of atoms gives some indication of the precision now attained.

Fig. 11 shows the chemical formula ($C_{63}H_{88}O_{14}N_{14}PCo$) for vitamin B_{12} which can now be written, as a result of the combined efforts of the organic chemists and the X-ray crystallographers.

The cobalt atom in the centre of the nucleus is linked to the benziminazole group on one side of the plane of the nucleus and to the cyanide group on the other side. The plane of the benziminazole ring system is nearly at right angles to the plane of the nucleus, but the ribose group attached turns back nearly parallel with the nucleus again. This allows for a return linking through the phosphate and

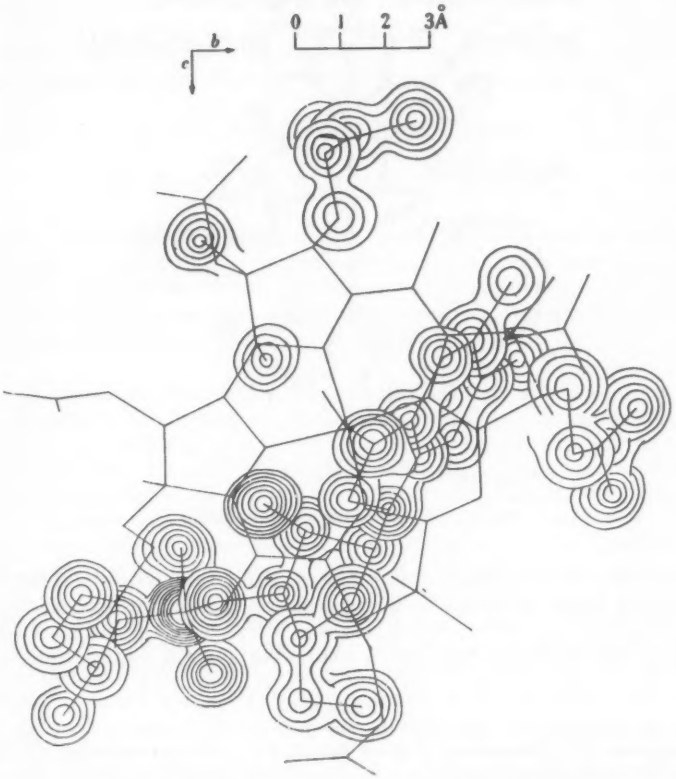


Fig. 10.—The remainder of the structure showing the benziminazole, ribose, phosphate and propanolamine groups, with some of the remaining side chains (D. C. Hodgkin *et al.*).

propanolamine group to the nucleus via one of the side chains (a propionic acid residue).

The whole stereochemical arrangement is an extremely compact one. Of the side chains, all the acetamide groups project towards the cyanide group, and all the propionamide groups project on the other side towards the benziminazole group. In general, all the atomic positions, which have been derived are found to conform to the very precise stereochemical rules which have been recognised from the study of much simpler organic systems.

This very precise and beautifully determined structure should now form a basis for the better understanding of the biological activity of the vitamin, its

relationship to the porphyrins and to porphobilinogen, and may also perhaps lead to its ultimate chemical synthesis.

I have dealt with this example at some length because it illustrates better than any other the enormous power of the X-ray method of analysis when applied to the solution of complex structures. The work is difficult and arduous, and it required the intuition of Dorothy Crowfoot Hodgkin to bring it to a successful conclusion. But when we remember the steady advances in technique which are taking place, and in particular the design of faster and more efficient electronic computers, we

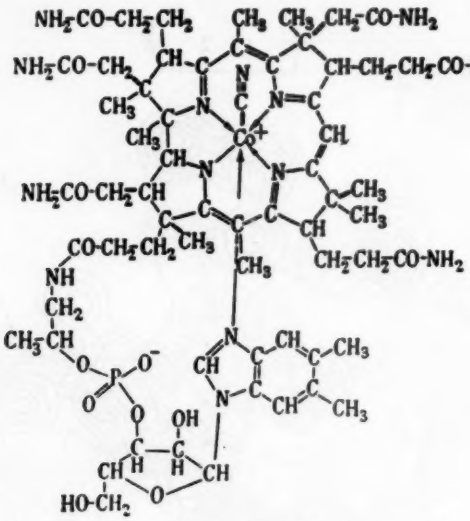


Fig. 11.—Chemical formula for vitamin B_{12}.

begin to realise what the effect of this new method on the future progress of chemistry is going to be. In determining the positions of atoms in space, which is to a large extent the basis of chemical knowledge, we have certainly moved a long way from those first fumbling steps which were taken about a century ago.

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THE BRITISH ASSOCIATION LOOKS AHEAD

Professor P. M. S. Blackett, F.R.S., President of the Association in 1957, considered—in an article published during the summer of 1958—the role of the Association in the world today. The text of this article (I), which also indicated some of the ways in which the Association was adapting itself to changed conditions, is printed in full below. It is supplemented by interim reports (II and III) on the progress of the inter-Meeting activities to which he referred.

I. THE BRITISH ASSOCIATION[1]

By Prof. P. M. S. BLACKETT, F.R.S.

In the future Britain must increasingly depend for her well-being on science and technology, with which a large part of the population must become in one way or another concerned. In this situation the British Association has an important part to play. The popularising of science was one of its main original objectives; it still is, but the audience is now different. Then it was a small, educated minority, now it is the whole nation.

The British Association has come in for some harsh criticisms in recent years, both from the world of professional scientists and from the body of scientific journalists. Though this bout of criticism is over, for the time being at any rate, and though it is commonly held that the now 127-year-old Association has recently undergone quite a bit of rejuvenation, it is worth recalling the gravamen of the criticism. In 1831 one of the main objectives of the newly founded British Association was what in modern jargon might be called 'the selling of Science to the Establishment'. Today this objective has long been reached, and in the abstract the Establishment is fully sold on Science, even though a little reluctant perhaps to pay the bill. Two further objectives were the diffusion of scientific knowledge both to a small world of professional scientists and to the larger but still relatively small world of interested members of the general public. The first of these two objectives has become much less important nowadays, since powerful scientific and professional bodies exist covering all the main branches of science, which publish their own specialised journals and organise regular conferences on a national and increasingly international scale. There are now so many of these specialised international conferences that some practising scientists are hard put, between attending scientific conferences, to do any new scientific work. Thus the British Association has not now, I think it is generally agreed, an essential role in diffusing scientific knowledge among the scientific professions, though it can do quite a bit towards widening the interest of specialists in one subject in other branches of science. Nor has it, as I have already emphasised, a decisive role in convincing the government of the day of the importance of science.

It would seem, therefore, that the main objective of the British Association must be in conveying science to the intelligent masses. Important as this is, by itself it might not be felt to form the basis for a rebirth of the British Association but for one very important factor. The fact that the country as a whole has woken up to the vital importance of science and technology to its future well-being has thrown up a number of new problems—or rather, has thrown new emphasis on old ones.

[1] Reprinted by courtesy of the Editor, from *Progress*, the Unilever magazine (May, 1958).

If a great nation like Great Britain is to retain its greatness and to enjoy a continually increasing standard of well-being, science and technology must be cultivated on a very big scale. This means that an increasingly large fraction of the entire population must become in one way or another concerned with science and technology. The administrator at his desk, the worker at his bench, the housewife in her kitchen, all are increasingly affected by a scientific and technological advance. Moreover, though only a few of these are directly engaged in scientific work, all are involved if only as parents of the next generation of scientists.

A government may decide that the country needs an increase in output of scientists and technologists of from 10,000 to 20,000 a year; this, however, can only come about if the country as a whole is educated up to the need. Much of this necessary education is, of course, available through official channels, from ministerial speeches and leading articles, from books and periodicals and from Ministry of Education policy propagated through the schools. But comparatively few people are made aware of these and there is still much that cannot be achieved in these ways, at any rate in Great Britain as it is at present. Voluntary work by non-official bodies has still clearly a very important role, and of these bodies the British Association, by its history, organisation and scope, has a particularly important part to play. As we have seen, the popularising of science was one of its main original objectives: it still is, but the audience is now different. Then it was a small educated literate minority, now it is the whole nation.

Many of the organisational changes now being made in the activities of the British Association are essentially connected with this widening of the audience to which it must address itself. In addition to the traditional Annual Meeting, which will always remain the central core of British Association activities, other activities extending over the rest of the year will be added. Many forms of such inter-meeting activity are now being discussed and being put into effect.

On taking office in January 1958 the President, Sir Alexander Fleck, announced the intention to form a panel of lecturers to address general audiences on scientific subjects. Already well over 100 scientists have agreed to join the panel and a number of lectures have been arranged, although the interval between the beginning of the formation of the panel and the summer recess was short. It is confidently expected that from September onwards the demands for lectures will increase rapidly, not only from the Area Committees mentioned below but also from organisations and schools in many parts of the country not covered by Area Committees. It was realized that the success of a scheme for the presentation of science to the public in any area would depend upon local support and local knowledge, and that the avoidance of duplication of effort and the provision of a suitable programme demanded a local organisation. Area Committees are, therefore, being set up to deal in the first instance with the lecture service. They will consist of a nucleus of scientists and representatives of teaching and professional organisations, on the one hand, and representatives of audience-producing organisations, such as Rotary, Women's Institutes, Townswomen's Guilds, Workers' Educational Association and Trades Unions, on the other hand. Committees have already been established at Newcastle upon Tyne and Tees-side and projects to establish further committees at Durham, East Anglia, Cornwall and South Wales are in various stages of development. The establishment of these Area Committees has been universally welcomed and they will play a vital part not only for the lecture service but also for the future development of the educational programme for young people, and the project for a Junior British Association. Special attention in all these activities will be based on influencing the young people of the country. In collaboration with local education authorities some very successful lectures to larger audiences of school children have already been organised and it is likely that during the coming year the demands for such lectures will exceed the financial resources available. An educational

programme is also under consideration for those under sixteen years of age. The programme envisages the use of various media for curricular, semi-curricular and extra-curricular activities in junior schools, secondary modern and secondary technical schools and grammar schools, and it is hoped to encourage by all possible means the development of science clubs. As soon as the financial position permits, action to implement this programme will be initiated. It is also proposed to organise Junior B.A. Meetings on a regional basis, a different centre in each region being chosen each year on the peripatetic model established by the Annual Meeting. As a first step towards this end, an extensive 'Young People's Programme' parallel with the Annual Meeting has been arranged at Glasgow this year.

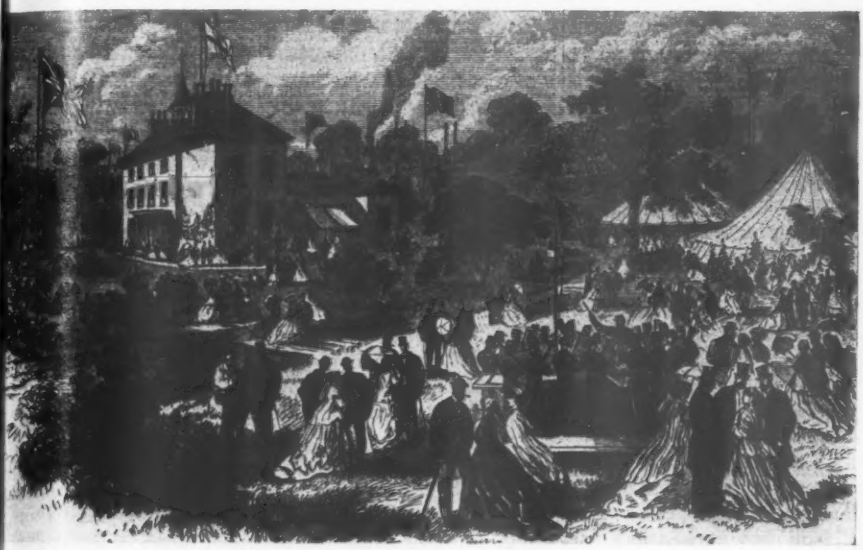

Fig.1.—The visit of the British Association for the Advancement of Science to Basford Park, Nottingham, in 1866. Such mixed gatherings sometimes aroused controversy. In an account of the Association's first meeting, in York in 1831, given in *The British Association—A Retrospect*, this passage occurs: 'The meeting took on a more formal aspect the following morning, when, on Brewster's motion, Viscount Milton, President of the Yorkshire Philosophical Society, took the chair. He addressed the assemblage as "Gentlemen", and thereby discovered a germ of future disputation; for women were not admitted to the earlier scientific meetings of the Association. This became a burning question. Buckland wrote to Murchison, in connexion with the second meeting: "Everybody whom I spoke to on the subject agreed that if the meeting is to be of scientific utility, ladies ought not to attend the reading of the papers—especially in a place like Oxford—as it would at once turn the thing into a sort of Albemarle-dilettanti meeting."'

Traditionally an activity of the British Association has been to take up at suitable moments matters of scientific importance to the community at large and to make a detailed study of them and subsequently make recommendations for action. An example of this was the part the British Association played at the end of the nineteenth century in setting up standards of physical quantities. Two new ventures of this kind are at present in progress. The first is a study of the metric system by a powerful committee, whose Chairman is Sir Hugh Beaver. It is hoped that within some months an authoritative report will be issued, weighing up the advantages and disadvantages of the much discussed and highly controversial question of whether Britain should switch to the metric system or not. It is expected

that the report will include estimates of the cost of so doing and by what various steps it could be carried out.

The second venture is the setting up of a study group on the educational system of scientists, under the chairmanship of Dr. R. P. Linstead, F.R.S., Rector of Imperial College. This group will pay particular attention to the problem of the education of the scientist through his school and university career. Special attention will be paid to the problems of the general education of the scientist and of the possibility of reducing specialisation at such an early age as is customary at present. The repercussions on the universities of any changed curricula in the schools will be investigated, and the economics and practical problems of making any recommended changes will be evaluated.

Atomic Science

The Association also organises conferences from time to time on subjects of national importance. The most recent of these was a Conference on Science in Schools held in the hall of the Royal Geographical Society in April this year and attended by over 700 headmasters, science masters, education officers, councillors and representatives of the universities and industry. The conference was concerned mainly with the two major problems of the supply of science teachers and the provision of adequate laboratory accommodation and equipment for schools. A report of the conference is being published by Messrs. Butterworth and will be available this September.

An interesting new activity for the British Association is to take over from the Atomic Scientists Association their function of presenting the facts and implications of atomic science to the people. A British Association Atomic Scientists Sub-Committee has been appointed and the machinery for the organisation of lectures and exhibitions on atomic science has been established and demonstration lectures have already been given to over 2,000 school children, and others have been arranged.

All these new activities of the Association will need a lot more money. Until last year its income was only £11,000 a year and a substantial deficit was being incurred. It is remarkable how efficiently the Association ran with so little money and a tiny paid staff housed in a very congested and entirely inadequate office in Burlington House. It only did so because of the devoted work of the General Officers and the secretaries and recorders of the Sections. The real life and initiative of the British Association for decades has resided in the Sections, and this is an admirable tradition which must always be preserved.

A first beginning was made last year to put the Association on a sounder financial footing by an appeal to a limited number of big industrial firms, who generously responded with the sum of £45,000 to be spent over about seven years. Another appeal is due shortly and is being organised by a committee with the President as Chairman.

The problem of accommodation has been solved too. The Royal Society of Arts offered the Association offices in their newly acquired building in John Adam Street and the Treasury, through the Ministry of Works, have generously agreed to pay the rent in respect of these offices, which became the headquarters of the Association this July.

Controversial Fields

There can be no doubt but that the years 1957 and 1958 will remain a landmark in the history of the British Association. A new and wider programme of activity has been inaugurated and the money and accommodation to initiate it has been provided.

The intimate relationship between science and the production and distribution

of wealth is well conveyed by the title 'Science and Business' Sir Alexander Fleck has chosen for his Presidential Address at Glasgow this year. No greater authority could have been found in this country than the one-time research chemist at Glasgow University and the now Chairman of Imperial Chemical Industries Limited.

However, the mere piling up of material wealth resulting from increased use of science and technology is not the whole story. Material wealth is, or should be, a means to personal health, happiness and contentment rather than an end in itself. It is quite possible for increasing material wealth to lead to increasing unhappiness. So we run right into many complex factors ranging from the subjective and psychological to the political and controversial. Controversy is no novelty to the British Association. The passage between Huxley and Bishop Wilberforce in 1860 is world famous. Commenting on the recent publication of Darwin's *Origin of Species*, Wilberforce was rash enough to ask Huxley whether it was through his grandfather or grandmother that he claimed descent from a venerable ape. To which Huxley retorted: 'If I am asked whether I would choose to be descended from the poor animal of low intelligence and stooping gait, who grins and chatters when we pass, or from a man, endowed with great ability and a splendid position, who should use these gifts to discredit and crush humble seekers after truth, I would hesitate what answer to make.' Prof. A. V. Hill in 1952, again in Belfast, stirred up much discussion by his forthright views on some of the outstanding moral and economic problems of the application of science. Controversy is inevitable when one discusses the uses to which science could or should be put.

Last year in Dublin I deliberately took a highly controversial theme, that of the effect of science and technology on the material way of life of mankind, in the past, the present and the future. I drew attention to the dangers resulting from the rapidly widening gap between the wealth of the rich and the poor countries of the world. I expected controversy and got it: most forthrightly from the scientific correspondent of the *Daily Express*. Critics such as this evidently thought I should have talked about my particular scientific interests, such as 'The Elementary Particles of Nature' or 'Cosmic Rays'. In my view these are subjects for the Sectional Addresses, not for the Presidential Address, for which a broader theme seems to me desirable. At intervals, no doubt, the overall history and outlook in each of the main branches of the pure sciences should be treated presidentially. But what I think the British Association audiences at the inaugural meeting prefer, and I think rightly so, is a discussion of some major problem of the application of science to human life. This may be on the mental plane—how has science altered our methods of thinking and behaving—then one is led at once into the controversial fields of philosophy, religion and morals. Or one can deal with the effect of science on the material way of life of mankind—then one is led right into the very heart of economics and political controversy.

Facts for the People

Clearly every possible attempt should be made by scientists to avoid giving unnecessary offence to people of different views, but it would seem to me unethical for a scientist to avoid any important aspect of the impact of science on the contemporary world just because different people may have very diverse views on the subject. Of course, the controversies within the field of pure science itself are often extremely important and interesting to pure scientists. In my own field of physics a few such problems can easily be listed: whether or no recent results in radio astronomy have indicated the need for a new cosmological model: whether the measurements of the magnetism of rocks has proved the frequent reversal of the direction of the earth's magnetic field: or whether a particular theory of the relations between the strange elementary particles of nature is true. All such

controversies are admirable subjects for the sectional proceedings of the British Association. But the general public, however intelligent, can hardly be other than spectators of the rival views of the contestants: nor, in fact, can most scientists working in other fields. For the degree of specialisation required even to grasp the essential nature of such controversies is now very great—much more so than was the case in the days when the Association was founded.

Thus if the proceedings of the British Association are to touch deeply the knowledge and feelings of the audience as a whole, they must often deal with the main ways in which science and technology are affecting the lives of ordinary men and women.

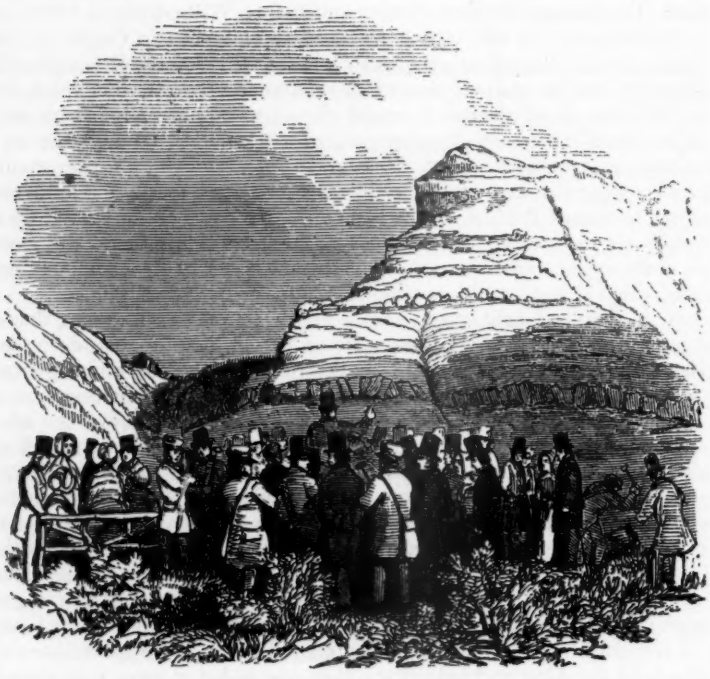

Fig. 2.—Dr. Fitton lecturing at Black Gang Chine, Isle of Wight, to the Geological Section of the British Association during its meeting at Southampton in 1846.

Broadly speaking then, there are three main aspects of modern science with all of which the British Association must concern itself. Firstly, science is a most exciting activity for its own sake for those professionals who practise it. In it one finds a fascinating mixture of experiment and theory, of manual dexterity and subtle thinking; and in few professions are so many sides of one's nature utilised to the full. Secondly, the vast body of knowledge and theory which modern science has created is without question one of the greatest and most exciting achievements of mankind, and provides continual intellectual interests for the non-specialist. Thirdly, modern science and technology is the greatest force for good or ill in the world today. Mankind has released vast forces of nature which he is still struggling to control. A knowledge of these forces and of the possibility of using them to improve the well-being of mankind is essential for every citizen who wishes to grasp the essential facts of the contemporary scene.

II. PRESENTING SCIENCE TO THE PUBLIC: INTERIM REPORT

Development of the new activities of the Association has made good progress since Professor Blackett described the position last summer.

Appeal for Funds

At the end of the Glasgow Meeting a second appeal was addressed to a large number of industrial firms for funds which would enable the plans to be implemented. As a result, the *total* income available to the Association over the next seven years is now of the order of £30,000 per annum.

Area Committees

The three prototype Area Committees established in the north-east, at Newcastle, Durham and on Tees-side, have arranged between them for the first season of operation over two hundred lectures. These have been addressed mainly to adult general audiences. The lectures have been carefully suited to the audience, and the range of subjects and the content of the lectures have been most satisfying.

These programmes can hardly fail to have a considerable regional impact. At the same time, much valuable experience has been gained. In some cases, the balance of a programme has not been beyond criticism, because the desire to tackle the problem together with the short time available to arrange programmes meant that the basis was 'first come first served'. As a result some enthusiastic customers have had more than their fair share of the programme, and some speakers with a ready-made lecture on a popular subject have been called upon more frequently than is really fair or, in the interests of a balanced programme, desirable. The committees are well aware of these matters, and are planning in their next programmes to achieve a better balance and more even coverage of their areas.

The work has revealed the great need for this activity; the professed aim was to fill holes where they were found to exist, but the pattern has been found to resemble the small boy's definition of a net—a lot of holes loosely tied together with string. There is evidence that, taking changing circumstances and demand into account, Area Committees can think ahead in terms of ten or fifteen years of most important work—and this limitation suggests itself only because the achievements of technology in mass communication in that period are difficult to foresee.

Perhaps the most remarkable feature of the Area Committee scheme has been the enthusiasm with which it has been launched and welcomed. The Association owes a great debt to the local enthusiasts, both organisers and speakers, who have given the work such an admirable beginning.

A Cornwall Area Committee was established at the beginning of the winter, and has planned as its first activity a three-day programme for school-children at Easter, at Liskeard and at Redruth. A meeting has been fixed at Nottingham in March, at which it is hoped that an Area Committee will be established; and it has been suggested that this Committee might organise a 'Junior B.A. Meeting' for school-children, much on the lines of the Young People's Programme put on at Glasgow at the time of the Annual Meeting last year. It is hoped that by the beginning of summer Area Committees will have been established at Birmingham, for the West Midlands area, and at Sheffield.

At Reading there is already in being a committee established under the Education Authority, which is engaged on exactly the same work, and in the Manchester area there is the Federation of Scientific Societies doing the same thing. In these cases, and in view of the statement in the first paragraph of the first chapter of the Statutes that the Association does not seek invasion of the ground occupied by any other institution, we are trying to help the existing organisations in their work.

Other projects of a similar or related nature have been discussed for East Anglia, South Wales, Bradford, Northern Ireland, Southampton, Worthing, and the Western Isles of Scotland.

Lecture Service

For places where there is no Area Committee or similar organisation, lectures are arranged from the offices of the Association, and the number of these has steadily increased.

Lectures for school audiences have been especially frequent, partly because it is easier to organise audiences from schools, and partly because of the very valuable work which can be done in this field. Fairly typical has been the collaboration with the Buckinghamshire Education Committee. First there was a lecture for some five hundred sixth-formers on 'The Peaceful Uses of Atomic Energy'. Then in December there was a three-day residential course for Arts sixth-formers at Shortenills camp. Five scientists spoke on physics, biology, and general topics such as the significance of science in modern life and world population in relation to food supplies. After each talk there was ample opportunity for discussion, both with the lecturer and later in study groups, and in the evenings there were film shows related to the day's lectures. Both these efforts were extremely successful, and are to be repeated. In January, Professor Dame Kathleen Lonsdale spoke to 400 sixth-formers at Slough on 'Crystallography'. Similar work has been done with schools in Cumberland, Lancashire, Kent, Sussex, Suffolk, Gloucestershire, Hertfordshire, Lincolnshire, Essex, Middlesex, Surrey and Merionethshire. Lectures have been given for under-16's as well as for sixth-formers, for science specialists, arts specialists and mixed groups; audiences have varied from gatherings of hundreds assembled from a number of schools down to the science club at a single school with a few invited guests for the occasion.

A number of lectures have also been arranged for adult audiences—Rotary, Workers' Educational Association, Women's Institutes, Townswomen's Guilds, Business and Professional Women, lecture societies and others. For example, two three-day programmes have been organised, in collaboration with W.E.A., to take place in Barnsley and Doncaster in March. Each will consist of two evening lectures, with an evening of scientific films in between. There have been other W.E.A. occasions in Hampshire, Devon and Hertfordshire, and it is hoped that in addition to single lectures and one-day or week-end courses, it may be possible to support systematic courses with lectures by scientists actually working in the field being studied.

Young People's Programme

The educational programme for those under sixteen, mentioned in Professor Blackett's article, has been launched through the generosity of the Shell Petroleum Company, who made a special donation to enable the necessary organisation to be set up. It aims to use the receptive and formative years from about nine or ten to fifteen, to ascertain and encourage scientific aptitudes where they exist, and where they do not to instil some understanding—which will never be lost—of what science is about.

A Planning Committee has been established under the Chairmanship of Sir Ben Lockspeiser, and two sub-committees are dealing with the specific projects of a science magazine for these young people, and of the development of science clubs. Both sub-committees have been putting in a good deal of basic exploratory work, and this must precede the emergence of firm proposals. There is however a sense of urgency in the work which promises well for the development of plans to meet needs as they are discovered.

It must be emphasised in connection with this programme that it is not the function of the Association to teach science, or to seek to interfere in any way with those who do teach it. It is a legitimate and important function to do anything possible to assist those who are teaching science without duplicating the work of agencies and institutions already in the field. It should also be recorded that it was in connection with this programme that the Association set up a Visual Aids Committee and engaged staff to service the Committee. This aspect of the work is described separately below.

Study Groups

The two other activities mentioned in Professor Blackett's article, the Metric Committee and the study group under Sir Patrick Linstead, F.R.S., have also developed rapidly.

The Metric System

The Metric Committee has now been at work for a year. Two Technical Officers have been working under the direction of the Chairman (Sir Hugh Beaver) and the Deputy Chairman (Dr. A. H. Hughes), and a great deal of ground has already been covered. In Britain, there has been close collaboration with the Association of British Chambers of Commerce, the Federation of British Industries and the British Standards Institute, with Ministries (particularly the Board of Trade, Ministry of Supply and Ministry of Education) and with nationalised industries. Questionnaires have been drafted and after testing in pilot surveys have been sent to Trade Associations, individual organisations, learned societies, public utilities, Commercial Attachés in the metric and non-metric countries abroad and to Trade Commissioners in thirty-six countries. After discussion with the American Association for the Advancement of Science, a parallel committee was established in the United States to consider the same problem. Decimalisation of the coinage has also been under consideration, and enquiries have been pursued with South Africa, Australia, New Zealand and India. In India the decision to adopt a decimal coinage was taken just before the Committee was established, and the first steps towards implementation are now being taken. The metric system has also been studied in relation to defence, air travel and life assurance.

The Education of the Scientist

Following Sir Patrick Linstead's acceptance of the Council's invitation to direct the work of the Study Group on the education of the graduate scientist in schools and universities, an approach was made to the Leverhulme Trust Fund and a generous response provided funds which should be sufficient to cover the whole of the work of the Study Group, which will be known as the Leverhulme Study Group of the British Association. The first meeting of the Group was held in November, and it is expected that the work will continue for some twenty-one months.

The Future Pattern

It seems clear that these new activities of the Association are meeting a genuine and pressing need and that they will form a permanent part of the Association's activities. For a number of reasons it is now necessary to undertake a revision of the Statutes—which will enable appropriate constitutional provision to be made for the new forms of organisation now in the process of development. The funds which industry has so generously provided must be regarded as 'priming the pump'; it is now up to the Association to ensure that its new activities will, as far as possible, be self-supporting.

III. PRESENTING SCIENCE TO THE PUBLIC: THE ROLE OF VISUAL AIDS

In 1958 the Council of the British Association invited representatives of the following organisations to serve with Council representatives on a Visual Aids Committee under the chairmanship of Sir Ben Lockspeiser: The Association of Women Science Teachers, the British Universities Film Council, Encyclopaedia Britannica, the Educational Foundation for Visual Aids, the London Institute of Education, Queen Mary College, the Science Masters' Association, the Scientific Film Association, the Shell Petroleum Company and Unilever Ltd.

Mr. Alec M. Hughes, M.A., formerly General Secretary of the Scientific Film Association, was appointed Visual Aids Officer of the British Association, and took up his duties on November 1, 1958.

At its first meeting on November 10, 1958, the Visual Aids Committee requested the Visual Aids Officer to make a preliminary survey of existing visual aids in relation to the Young People's Programme.

This survey was concerned with the organisations in the field capable of producing and using material; the kind of material available for teachers and lecturers; suggestions from those consulted about needs which could be met immediately and others which ought to be met in the future.

Of necessity it was only a cursory examination of a vast field, based on consultations with members of the Visual Aids Committee, with representatives of the principal organisations concerned with visual aids, and on discussions with representatives of a number of bodies which share with the British Association an interest in the promotion of scientific knowledge among wide sections of the public.

The survey was related to the needs of the Young People's Programme, which is based on three main assumptions:

1. That the most powerful single weapon would probably be a magazine designed to present science attractively and authentically to young people. It is accepted that such a magazine would have to be a commercial production and that the aim should be to persuade a publisher to produce such a magazine, and to give the publisher such help in procuring material, in promotion and in reader-reaction as may be possible.
2. That it is also necessary to give the schools all possible help. In certain cases this will be within the curriculum, but generally it seems that semi-curricular and extra-curricular activities may provide the best opportunities for success, and in particular the promotion of Science Clubs in schools by every possible means.
3. That Science Clubs will require all assistance that can be given, and this means visual aids. A very great deal is already being done, but there seems to be a need for co-ordination, for letting schools know what is already being done and seeing that they get what they want, and for procuring the production of suitable specific material for the campaign.

There was widespread approval of the interest shown by the British Association in visual aids, in the belief that this will result in a more effective use of visual material by specific, well defined groups.

Many aspects of the problem of presenting science visually were discussed informally with representatives of some fifty organisations—including learned and professional institutions, industrial organisations, educational bodies, scientific and visual aid journals, and visual aid producers and distributors. Visual presentation is of direct or indirect interest to widely differing organisations concerned with the teaching of science to young people. It might be a distinguished body such as the Royal Institution, whose lecture-demonstrations enjoy a reputation commensurate

with their outstanding quality. It might be an organisation like the Institute of Physics, which in April 1959 is organising a conference on the teaching of physics to children under fifteen. It might be an educational establishment like the Oxford Institute of Education which is arranging a conference to take place in July 1959 on 'Science as a general study in the VIth form'. It might be an Extra-mural Department of a University, a W.E.A. District Committee, a Young Farmers' Club, or the science club of a secondary school.

Among them all the need for detailed information about visual aids is evident and often keenly felt. But of course much of the necessary information is already provided in one form or another by existing agencies, and the British Association can make a significant contribution here not by the needless duplication of effort but by complementary activity and the careful co-ordination of the work already being undertaken, in so far as this meets the needs of the Young People's Programme.

The problem is a complex one. For example, more than 8,000 schools have projectors. But are they used as effectively as they might be—indeed in certain circumstances are they used at all? Why do other schools lack such equipment? Films there are in abundance, but are they necessarily the right kind of films? The Royal Institute of Chemistry has compiled a list of more than 800 films and film strips concerned with chemistry. Yet it has noted specific aspects of the subject for which no suitable film or film strip exists. In how many other fields of science does a similar situation obtain?

How effective are the visual aids which do exist? Views differ markedly and one could quote some of the arguments on the relative merits of film strips and slides. On the one hand, organisations like the Educational Foundation for Visual Aids and Hulton Educational Productions report an increasing demand for film strips, and bodies like the Royal Institute of Chemistry are now entering the field of production through existing agencies. On the other hand, the Association of Women Science Teachers supports the view that slides are gaining ground because of their flexibility—a view also subscribed to by the British Iron and Steel Federation which has now started producing slides to supplement its film strips in response to demand from Education Officers in steel works. Here is but one instance of the problems which require detailed investigation.

The economic aspect provides a further example. Recently a large industrial concern printed a brochure for its shareholders which cost 12*s*. 6*d*. per copy to produce. The same organisation sponsored a film of general scientific interest whose initial cost was 25 per cent more than the brochures. But the film has been shown to well over a million people and has cost perhaps 1½*d*. for each person who has seen it. We are all familiar with the fact that a single television programme may be seen by millions, a brilliant lecture-demonstration repeated once or twice at the larger of our public halls by only a few thousand. Yet the latter may have involved research and the preparation of equipment over a period of many months —a costly enterprise.

Whilst one cannot measure educational value by counting heads in this way one must recognise that economic factors are a major consideration in any educational project and particularly so with visual aids which may be expensive to produce.

There is, of course, an abundance of visual material concerned with science—hundreds of sets of wallcharts; models and demonstration equipment; films on subjects like mathematics (a small number of specialised productions), automation, optics, polar exploration and research (on each of which subjects there are over 100 films), agriculture (over 600 films), chemistry (nearly 800 films), or medicine (nearly 2,000 films).

The British Association is already making use of this material—providing visual aids in connection with the Young People's Programme; arranging film programmes

in connection with the York Meeting and with both residential and non-residential courses; and informing scientists about available material suitable for their needs. Visual material is, of course, best used if carefully integrated with other activities. For example, it may be possible to arrange a programme of suitable films as one session in a course. But it is obviously much more effective if the Director of Studies and the lecturers have detailed information about the visual aids to be used and plan their material to link specifically with such aids.

If work of this kind is to be further developed more precise information is required about the contribution visual aids can make to the Young People's Programme. The British Association is, therefore, to make a detailed survey, the results of which will be published in a comprehensive report. No report of this kind exists and it was felt that the Association would perform a major service by providing an impartial survey which:

(*a*) Outlines the role of existing agencies.
(*b*) Publishes comments by those working in the field on the use and suitability of existing aids.
(*c*) Makes recommendations, after close consultation with existing agencies and individual experts, for action to be taken to promote the better use of available material and the production of new material.

The findings of this survey would provide a basis not only for activity by the British Association but also by the many existing visual aid agencies.

The completion of this report would not, however, mark the end of the survey, which must be a continuing activity if it is to provide regular information which will enable the sponsors and producers of visual aids in consultation with science specialists to provide material appropriate to the ever-changing scientific and technological needs of contemporary Britain.

PROSPECTS AND PROBABILITIES IN ELECTRONIC DATA PROCESSING[1]

by

DR. ANDREW D. BOOTH

THE first stored-programme electronic digital computers were projected about twelve years ago and, at this time, it was confidently expected that they would be in full operation by, say, 1947 or 1948. In the event this expectation was not fulfilled and it was not until the early 1950's that the first machines came into somewhat limping operation. It is only about four years since really reliable operation has been attained.

There was one main cause for this delay between conception and operation and this was the total underestimate made by designers of the difficulty of producing a reliable store. This is well illustrated by an experience of the present author when visiting a large American computer laboratory in 1947, the director was asked what form of storage he was going to use and replied to the effect that he had not yet bothered to think about this too deeply as it was an easy problem which would be solved when they came to it. The machine produced by this group was one of the last to come into operation.

The root of the trouble with storage media was, then as now, that the ratio between the power required to insert data into the store and the power recovered when data are read out is about 10^6:1. It is the amplification which is required to make good this attenuation, and its attendant liability to pick up spurious signals, that made the storage problem so intractable.

Naturally a statement of this kind requires more detailed exposition than can be given here, but it is sufficient to say that early workers in this field believed that no store which depended for its operation on physically distinct storage elements would be economically feasible. This statement, whilst true in the large, is certainly untrue in detail as recent developments have shown and the point will be taken up again later in this paper.

From the early 1950's until about 1955 the applications of computing machines were almost exclusively in the fields of mathematics and science and it is only in the last two or three years that commerce and industry have taken a really active interest in potential uses. In science many branches of research have been revolutionised. Thus crystal structures whose calculations once took three years to complete can now be analysed in as many weeks and, what is even more important, structures, such as those of the vitamins and proteins, which were formerly far too complex for analysis, have now been brought within the realms of achievement. Like remarks apply to a less extent in situations which involve the solution of sets of linear simultaneous equations and these include many problems where solution depends upon ordinary or partial differential equations and upon the solution of integral equations. Examples occur in the theory of structures, in fluid dynamics, in the design of power reactors and in economic planning.

In the business field applications were slow to be made, and it is an indication of the lack of intelligence and foresight of financiers in this country that, with minor exceptions, no support has ever been given to computer development by these people. As an example of this parsimony may be mentioned the Banks, whose

[1] Paper delivered to Sub-Section A* (Mathematics) in a symposium on 'The use of electronic computers' on August 29, 1958, during the Glasgow Meeting of the British Association.

representatives have more than once stated that they are eager to use electronic automation—if someone else spends his money upon its development.

We now turn to an examination of present and future needs in calculation and calculators. Naturally the argument can proceed only by considering some of the problems already solved and this, to a certain extent, is a risky procedure. However, since the results will be seen to be consistent, the deviation from truth is probably small.

In the scientific field we take three examples. The first is the solution of a problem which leads to a hyperbolic partial differential equation with spherical symmetry in the spatial variables. A concrete example is the propagation of the blast wave resulting from an atomic explosion. Here it turns out that about 3,000 time-steps are required, over a radial distance which is divided into 100 space-steps. The number of equivalent multiplications needed for each time-step and radial point is 60, so that, in all, about $1{\cdot}8\times10^7$ multiplication times are involved for a single run of the problem. Actually a check run would also be made so that a more realistic figure is 4×10^7 multiplication times. A solution to a single problem of this type would usually be valueless and a run of, say, 10 such solutions would be a fair assumption, the total number of multiplication times is thus about 4×10^8.

The problem just mentioned is a highly idealised one and more interesting situations would consider the problem of a blast wave which originated at a point on the earth's surface. If it is now assumed that the system has cylindrical symmetry the figure given above is increased to 3×10^{10} multiplication times and if no symmetry is present the figure increases to 3×10^{12}.

In this particular problem the number of data to be held in store are about 5 per spatial-point so that, apart from the programme, the one-dimensional case requires storage for about 500 numbers the two-dimensional case for about 4×10^4 numbers and the three-dimensional case for about 2×10^6 numbers. To derive the figures no assumption has been made that the space subdivision can be made less than one-hundredth of the total interval. In practice the two-dimensional problem might use an interval of one-fiftieth and the three-dimensional one an interval of one-twentieth, so that lower bounds to the above values are 500, 10^4 and $1{\cdot}6\times10^4$ stored quantities.

The second class of problem is one which leads to an elliptic partial differential equation, typified by relaxation calculations in the field of continuous structures. Here, for a subdivision of one-hundredth, and an assumption of 20 iterations per solution, and 20 multiplications per point, we obtain figures of 10^4 for storage requirement and 4×10^6 for number of multiplications. In three dimensions these figures become 10^6 and 4×10^8 respectively even without allowing for the fact that convergence is likely to be slower in the more complex situation.

For the crystallographic problem, in the field of protein analysis, it may be necessary to evaluate the sum of a Fourier series with 10^4 terms at each of about 10^5 points, each term requiring, say, 5 multiplication times. The total is thus 5×10^9 multiplication times for one run and up to 10 runs may be needed to complete the determination, so that here we arrive at a figure of 5×10^{10} for total number of multiplication times. Storage, in this case, may vary from 10^4 to 10^6 numbers.

As a bridge between science and commerce we can consider the problems of machine translation of language. Here the requirement is not so much for speedy arithmetical operations but rather for programme and data storage. From the work so far carried out it appears that between 10^5 and 10^6 words will be adequate and that the processing time, even with existing machine speeds, is negligible.

When we come to the field of present-day commercial applications we find a most pedestrian collection of uninteresting tasks which appear to have sprung from the minds of form-fillers inspired by government edicts which seek to foist the burdens of fiscal administration more and more on the citizen. P.A.Y.E. is a

typical example and is so uninteresting that we shall not consider it further. Account keeping in the banks is another example of a business task. Existing computers are not directly suitable for application here, because of inadequate peripheral equipment and buffering, but an analysis of the volume of work involved leads to figures roughly two orders of magnitude less than those which appear in the scientific examples cited above.

The interesting computer application in business lies in economic planning and prediction. The computational techniques involved are those of linear analysis and a typical small industrial firm would require, for its correct optimisation, the solution of sets of linear equations and inequalities which involve a storage of perhaps 10^5 numbers and the performance of 10^8 multiplications.

With these estimates before us we are in a position to examine the adequacy of existing computers for solving the problems posed. Before this is done, however, it is necessary to say a few words regarding the instruction times which are involved. All of the above estimates have been made on the basis of a ratio of one multiplication to 5 other operations and a multiplication time which is 20 times as great as that of an addition or transfer. This fits well enough with the structure of most well-balanced modern computers but there is an increasing tendency to produce machines in which multiplication and addition times may differ by factors of two or three but certainly not by 20. It would be difficult to estimate exactly the effect of this structural change on the computing speed of future machines but the following approximate argument is probably not too far from the truth. Present scientific calculations seem to involve about one multiplication to nine other operations thus, for N operations the computing time is about

$$m.\frac{N}{10}+p.\frac{9N}{10}$$

where m is the multiplication time and p the time, inclusive of storage access, of other operations. Suppose that, for present machines $m/p=20$ and for machines of the future $m/p=2$, then if T_0 is the present time for N operations and T_1 that of a future machine

$$T_1 \approx (4M/m)T_0$$

where M is the multiplication time of the future machine. The implication of this is that the change in internal balance will not result in so great a saving of time as might be attained by putting an equivalent effort into increasing the speed of addition and transfer operations.

To consider a typical example one existing machine has $m=400$ μsec., $p=20$ μsec. On this the time for 10^{10} equivalent multiplications would be about 1,100 hours, which is far too long for any hope of a correct result.

A very recent American project, designed to extract the greatest possible speed from existing techniques, aims at producing a multiplication time of about 2 μsecs. With this will be associated an addition time of about 1 μsec., so that the time for our equivalent operations becomes $1100\times4\times\frac{2}{400}$ hours, that is, about 22 hours. This is reasonable but not as good as the $5\frac{1}{2}$ hours which would be needed if non-multiplication functions could be speeded up to $\frac{1}{4}$ μsec.

These figures also show the class of problem which is amenable to treatment with existing machines. Thus, with $m=400$ μsec. the one-dimensional blast investigation takes about 44 hours—which is practicable, the two-dimensional variant takes 3,300 hours or 138 days, which is just beyond possibility, and the three-dimensional version would take about 25 years. Relaxation problems in three dimensions are quite practicable as far as computing time is concerned but

the protein crystallographic problem is just beyond range. Finally, the problems of small-scale factory planning are well within range.

With the advanced machine having $m=2$ μsec., $p=1$ μsec., all of the problems discussed become tractable with the exception of the three-dimensional blast which would still need about 190 days of computing time.

So far no mention has been made of the storage problem and it has been tacitly assumed that adequate storage of suitable speed is available. This, unfortunately, is not so. No store of access time better than 1 μsec. is available at present and physical conditions suggest that the best which can be expected is a magnetic matrix, using thin film techniques, which will give access times of about $\frac{1}{4}$ μsec. Such storage is, in any case, costly so that we come to envisage a machine which has several levels of storage each of slower speed than its predecessor. The sizes of these storage organs can be calculated approximately by considering the number of operations to be performed upon each datum before the next is required. In our earlier examples we saw how this varied from 5 in crystallography to 60 in the blast problem and, if we take the worst case, this implies that the first backing store might be five times slower than the high-speed store. This, however, does not appear feasible if the latter has read out times of order $\frac{1}{4}$ μsec., so that several backing stores of magnetic drum type would have to operate in parallel and the organisational problems involved in synchronising the system mathematically would be considerable.

For these reasons it appears that, unless some new discovery in the field of high speed storage is forthcoming, we shall be limited in the solution of certain classes of problem. These limitations do not yet obtrude in the business field but are already present in scientific applications. No fundamental discovery has been made in computer technology for the past seven years and even technical advances have been slow, the transistor for example is much talked about but little used and, in any case, needs much development before it can be applied in ultra high-speed machines.

This is, perhaps, a gloomy picture and it would not be well to dwell upon it, instead we will conclude by considering the limiting speed of a future computer using techniques as yet undiscovered. This can be determined from the following considerations:

1. The number of logical elements in the computing unit.
2. The velocity of light (3×10^{10} cm./sec.).

For binary machines of word-length 32 bits, the number of logical elements can be shown to be about 500. If it is assumed that, by miniaturisation and other technical advances, one such element could occupy 1 sq. cm. of area, the transmission path from edge to edge of the machine unit should not exceed 30 cm., so that the addition time of the machine might be as low as 10^{-3} μsec. Multiplication could not be accelerated by parallel operation in a machine of this size and speed and a fair estimate of multiplication time might be 2×10^{-2} μsec.

With these figures all of the problems which we have considered come easily within the range of solvability and we leave it as an exercise to engineers and physicists to produce the necessary hardware.

BACTERIA AND INSECTS[1]

by

DR. J. R. NORRIS

THERE are so many bacterial diseases of insects and so many examples of micro-organisms living in the bodies of insects in some sort of parasitic or symbiotic relationship, that I shall not attempt to make any broad generalisations about insect-bacteria relationships. Instead, I shall restrict myself to one corner of this very big subject because it promises to throw light on questions which have long fascinated and puzzled the bacteriologist and others.

The story does not as yet have an ending. What I want to do is not so much to give an account of work done and results obtained but rather to explain some of the ideas behind our approach to the subject and to try to show where we hope it is going to lead us.

In 1915 the German bacteriologist, Berliner, came across some diseased larvae of the meal moth (*Ephestia kühniella*) and isolated from them a bacterium, an aerobic, rod shaped, spore-forming bacterium, which he showed to be the cause of the disease. The meal moth (or flour moth as it is often called) can be a great pest in flour mills and grain stores. The adult lays its eggs in large numbers on the surface of the flour and these hatch to form larvae which tunnel down into the flour causing considerable spoilage. Berliner was eager to try to use his bacterium, which he called *Bacillus thuringiensis*, to control the moth. A spore-forming bacterium is a very convenient biological control agent and the possibility of using this bacterium to control the flour moth and other insect pests has been a constant and valuable stimulus to research.

Berliner made a careful study of his bacillus and soon noticed a rather unusual thing about it. As a culture, growing on a nutrient agar plate, became old the vegetative bacterial cells began to produce spores in the usual way; but, instead of the rest of the cell contents gradually disappearing until only the spore was left, as would normally happen with a spore-forming bacterium, a second body developed within the bacterial cell alongside the spore. What was even more surprising was that this body assumed a regular rhomboidal shape (Fig. 1).

No one really took much notice of this structure until a few years ago when Hannay in Canada rediscovered it and carried out a thorough study of it (Hannay, 1956). The granules were indeed regular rhomboidal crystals and on chemical analysis proved to be protein in nature. This was immediately interesting. In Nature, protein crystals are by no means common and not a great deal is known about their structure and synthesis. Did these crystals play any part in the disease process?

In 1902 Japanese workers isolated an aerobic spore-forming bacillus from diseased silkworms and called it *B. sotto*. They showed that it produced a toxin which affected the silkworms and which was associated not with young vegetative cells but with old, well sporulated, cultures. A new study of strains of *B. sotto* showed that it, too, produced protein crystals. Did these crystals have any connection with the toxin? The answer came in 1954 from Angus, also working in Canada.

Angus took an old culture of *B. sotto* and extracted it with silkworm gut juice. He then removed the spores by filtration and showed that the fluid left contained a substance which, when fed to larvae, caused paralysis and death. The gut contents

[1] Paper contributed to a joint session of Sections I (Physiology and Biochemistry) and M (Agriculture) on Host-parasite relationships, on September 3, 1958, at the Glasgow Meeting of the British Association.

of these larvae are very alkaline and it can easily be shown that the protein crystals go into solution in dilute alkali. Angus then separated crystal protein from spores and tried the effects of feeding and injecting various fractions.

When an old culture consisting of spores and crystals was fed to the larvae there was first a paralysis and then the bacteria passed through the gut wall into the body cavity to produce a septicaemia. If the same culture was injected directly into the body cavity bacteria multiplied there to give a septicaemia—but there was no paralysis. When spores alone were fed there was no invasion of the body cavity but septicaemia developed if they were injected directly into the body cavity. Crystal protein by itself caused paralysis on feeding but not on injection. It seems that:

(1) Crystal protein is necessary for the penetration of the bacterium through the gut wall.
(2) The protein needs to be activated by the gut juice before it becomes toxic.

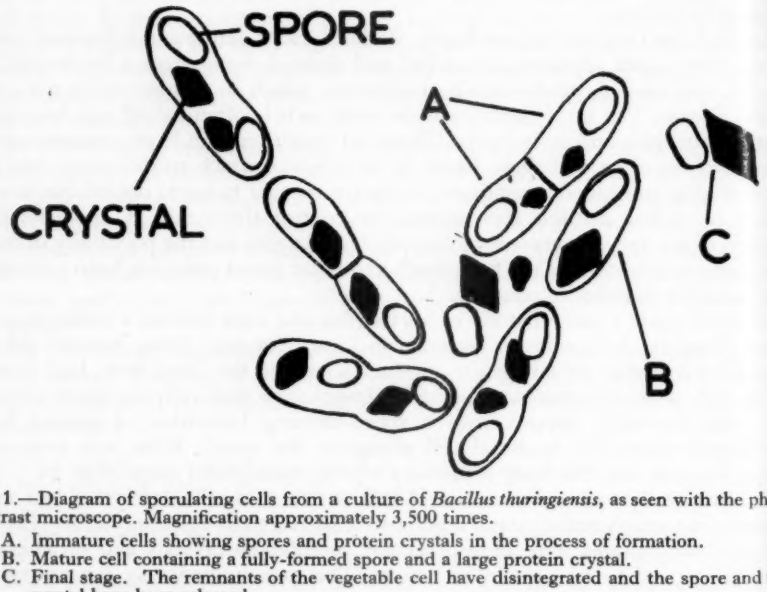

Fig. 1.—Diagram of sporulating cells from a culture of *Bacillus thuringiensis*, as seen with the phase contrast microscope. Magnification approximately 3,500 times.

A. Immature cells showing spores and protein crystals in the process of formation.
B. Mature cell containing a fully-formed spore and a large protein crystal.
C. Final stage. The remnants of the vegetable cell have disintegrated and the spore and the crystal have been released.

Here then we have an interesting, complicated, not yet fully understood, host-parasite relationship.

B. thuringiensis, *B. sotto* and a few other bacteria producing disease in various insects are all very similar to one another and, as a group, bear a striking resemblance to a common saprophytic bacterium *B. cereus*, which abounds in soil, dust and other natural environments. The only real difference between the insect pathogens and *B. cereus* is that *B. cereus* fails to produce protein crystals and is of course incapable of causing disease.

So close is the similarity that we might well ask, 'Could it be that the insect pathogens represent strains of the saprophyte which have in some way become adapted to a parasitic—and indeed pathogenic—mode of life?' This adaptation would of course involve the development of the ability to synthesise this peculiar crystalline protein. This is the crux of the whole matter. If, in the laboratory, we

could take strains of the saprophyte and, by subjecting them to suitable conditions, render them pathogenic and capable of crystal synthesis we should be a big step nearer to understanding some of the mechanisms underlying the parasitic mode of life of these bacteria and to understanding the factors which lead to the development of the parasitic habit. We should indeed be cultivating fields of knowledge about which we know very little.

In the laboratory the insect pathogens sometimes lose their virulence and crystal-synthesising abilities. Then it is impossible to distinguish them from *B. cereus*.

Recently workers in France tried the effects of injecting saprophytic strains of *B. cereus* into the body cavity of larvae of the wax moth (*Galleria melonella*) a common source of annoyance to bee-keepers. The larvae developed a septicaemia and died and the bacterium was then re-isolated from the body fluid. The process was then repeated with this isolate and so on. After a few passages of this kind the bacterium started to become pathogenic for the larvae when administered by mouth and, under the microscope, could be seen to be producing crystals. This has been confirmed independently by another group in France and it seems that feeding weakly pathogenic strains to the larvae and re-isolating them from the body cavity may also enhance their virulence (LeCorroller, 1958).

Now experiments of this type are far easier to describe than to perform and I should not like to give the impression that this sort of transformation is proved up to the hilt. There is much checking and rechecking to be done. It is interesting, however, to compare these observations with some recent American work on the anthrax bacillus. *Bacillus anthracis* is another aerobic spore former closely related to *B. cereus*, differing from it mainly in its ability to invade the body of a susceptible animal and cause disease. Recently a group of bacteriologists in the United States took non-pathogenic strains of *B. cereus* and grew them on culture media containing blood of young rabbits. After several passages on this medium the bacteria became virulent and were capable of causing anthrax in a variety of hosts. Here, of course, there is no question of crystal synthesis (Brown *et al.*, 1958).

We know that *B. thuringiensis* and the anthrax bacillus can produce avirulent mutants in the laboratory which it is virtually impossible to distinguish from *B. cereus*. Can we go the other way and convert saprophyte to parasite?

B. cereus is a very common saprophyte and both insect larvae and higher animals must often come into contact with it. Do variants of the saprophyte arise which are capable of invading the bodies of various hosts? Are the hosts able in some way to induce pathogenicity in the saprophyte? How does the crystalline protein of *B. thuringiensis* render invasion of the larval tissues possible? Is the protein activated by the larval gut contents, and if so, how? How is it synthesised by the bacterium?

The first step in any research project is to ask clear fundamental questions. We hope that this description would apply to the questions which we are asking ourselves at the moment. If so, we may reasonably expect that useful answers will follow. If we succeed, we shall certainly understand this particular host-parasite relationship more fully; perhaps it is even more important that we may find ourselves closer to appreciating some of the principles involved in the development of this type of relationship and even, on a wider scale, the development of the pathogenic habit from the saprophytic in bacteria.

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NITROGEN METABOLISM IN PLANTS

SECTION K (Botany) devoted the afternoon session of Friday, August 29, 1958, at the Glasgow meeting of the British Association, to a discussion of nitrogen metabolism in plants. Dr. G. Bond (University of Glasgow) indicated the present state of knowledge regarding the incidence among plants of the faculty for the utilisation of elemental nitrogen, and paid particular attention to the occurrence of this fixation of nitrogen in the root nodules of certain widely-distributed non-legume plants. Dr. G. Leaf (University of Glasgow), in a paper closely linked with the preceding one, discussed the chemical mechanism of biological nitrogen fixation and presented new findings relating to the non-legume root nodules, hitherto uninvestigated from this aspect. Dr. L. Fowden (University of London) widened the scope of the discussion by his paper relating to the assimilatory processes by which inorganic nitrogen compounds are incorporated into amino-acids and proteins in plants in general. In the preparation of the following somewhat shortened versions of these papers certain minor editorial duties have been discharged by Dr. Bond.

THE INCIDENCE AND IMPORTANCE OF BIOLOGICAL FIXATION OF NITROGEN

By G. Bond

By biological fixation of nitrogen we understand the ability of certain organisms to base their nitrogen nutrition on the elemental nitrogen which is present in such large quantities in the atmosphere and in water in contact with the atmosphere. The first act of such organisms is to bring the elemental nitrogen into combination, i.e. to 'fix' it. Some writers have regarded this fixation of nitrogen as one of the basic processes of the living world, along with photosynthesis and respiration, their argument being that without it the supply of combined nitrogen in the soil and in the ocean would eventually become exhausted, owing chiefly to the action of denitrifying bacteria.

The classical method for the detection of fixation is to test whether the organism under examination can grow and increase its nitrogen content when it has no access to combined nitrogen, a method which has been used for all types of material, ranging from micro-organisms to higher plants. A more recent method (first used by Burris & Miller, 1941) in which the isotope of nitrogen, ^{15}N, is employed depends on two basic considerations. Firstly, that the nitrogen of the nitrogenous constituents of living organisms is normally nearly all ^{14}N, only one in about every 267 nitrogen atoms (or 0·375 atom per cent) being ^{15}N. This proportion of ^{15}N is also present in the nitrogen of the atmosphere. The second point to be noted is that the living organism does not distinguish between the two forms of nitrogen. Thus a nitrogen-fixing organism will fix both kinds of nitrogen equally readily. If, now, an organism is exposed for a period to elemental nitrogen containing an artificially increased proportion of ^{15}N—say 10 atoms per cent—then if fixation occurs the cells of the organism will acquire a higher content of combined ^{15}N than the normal 0·375 atom per cent. The determination of the ^{15} content requires a mass spectrometer; the ^{15}N method is much more sensitive than the first method and has certain other advantages.

In reviewing the incidence of fixation it is convenient to distinguish between

fixation in independently growing, asymbiotic organisms and that shown by symbiotic systems.

Evidence derived chiefly from the older, long-term growth technique indicates that no (or no significant) faculty for fixation resides in such members of the Angiosperms, Gymnosperms, Pteridophytes, and Bryophytes as have been examined, except where there is symbiosis with certain lower organisms. The question of whether Angiospermous crop plants such as cereals, crucifers and sunflower can use elemental nitrogen was of course closely studied in classical investigations of the nineteenth century. In general, the finding was that these plants, when germinated in a rooting medium such as ignited sand, quite free of combined nitrogen, entered into a state of nitrogen starvation once the seed nitrogen had been used, and remained in it unless combined nitrogen was supplied. Nitrogen balance sheets showed no significant gain. This finding has doubtless received confirmation in countless experiments at research and class-room level, and is generally accepted. Similar evidence can be found in the literature in respect of conifers, ferns and mosses.

The contrary view has not lacked its occasional advocate in modern times; thus Schanderl (1947) claimed, on the basis of sand cultures, that a wide range of Angiosperms can fix nitrogen. Some of his types, such as blackberry, sycamore and walnut, had probably never been tested before, but to claim that cereals and sunflower can also fix nitrogen is so contrary to normal experience as to make confirmation of the rest of the observations desirable.

Moving further down the plant kingdom, the Algae have received considerable attention. There is of course satisfactory evidence that some though not all blue-green Algae can fix nitrogen, especially members of the genera *Nostoc*, *Anabaena* and *Cylindrospermum* (Fogg, 1956). The fixation is sufficient to permit of vigorous growth in media free of combined nitrogen. There have been several extensive investigations with green Algae, particularly *Chlorella*, *Stichococcus* and *Scenedesmus*, with negative results (e.g. Bristol & Page, 1923).

There is an extensive and confused literature on fixation in fungi which has rarely been critically examined, but here only a brief statement is possible. There have been several reports of fixation in the genus *Phoma* (Ternetz, 1907; Duggar & Davis, 1916; Jones & Smith, 1928), but a careful study of these papers leaves one feeling that further studies are desirable. Baker's yeast has given consistently negative results by the ^{15}N technique (Lindstrom, Lewis & Pinsky, 1951), but Metcalfe and his co-workers (1954, 1957) have presented evidence for fixation in certain soil yeasts. A tentative conclusion is that while the nitrogen nutrition of most fungi is based on combined nitrogen, there is preliminary evidence that certain fungi have some power of fixation.

The bacteria may fairly be said to include the main nitrogen-fixing organisms. Well-known examples are provided in the genera *Azotobacter* and *Clostridium*, though it is a common view that fixation by these heterotrophs is often severely limited by the level of organic matter in the soil. *Rhizobium* and the possibly bacterial endophytes of certain other root nodules will be considered with symbiotic systems. Other bacteria for which there is good, or at least some evidence of fixation include *Azotomonas*, *Aerobacter*, *Desulphovibrio*, *Methanobacterium* and *Pseudomonas*. Also, it has been shown that certain bacteria, including *Rhodospirillum*, *Chromatium* and *Chlorobium*, which had previously been distinguished as possessing chlorophyll and the ability to photosynthesise, have the further characteristic of nitrogen fixation. In ^{15}N tests by workers at the University of Wisconsin certain well-known bacteria have given negative results, including *Escherichia coli*, *Agrobacterium radiobacter*, *Hydrogenomonas* and *Proteus vulgaris*.

We come now to fixation by symbioses, and in many of these a heterotrophic, nitrogen-fixing organism is intimately associated with a photosynthetic partner,

giving a highly independent unit with strong pioneering potentiality. The indications are that in many habitats symbiotic fixation is much more important than that of asymbiotic type.

The best-known example is provided by the legumes, where the root nodules normally present contain dense growths of the bacterium *Rhizobium*. Sufficient fixation typically occurs in these nodules to make vigorous growth of the legume possible in a rooting medium free of combined nitrogen. In the past, fixation by legumes has been a basic process in agriculture, and still is so in some countries, for example New Zealand, but in the more highly-industrialised countries legumes are being displaced by fertiliser nitrogen.

As regards areas of natural vegetation there is mounting evidence that a second group of Angiospermous root nodule plants are often more important than legumes. I refer to eight genera, namely *Hippophaë*, *Elaeagnus*, *Shepherdia* (these three forming the family Elaeagnaceae), *Myrica*, *Casuarina*, *Coriaria* (all of which are in monogenic families), *Alnus* and *Ceanothus* (these two belonging to families not otherwise nodulated). These genera are all woody and include some very widespread plants, but the significance of the root nodules which they normally bear had received little attention until studies were commenced in the writer's laboratory a few years ago. The results obtained indicate that the nodules are completely analogous to those of legumes in function; nodulated plants, but not those without nodules, are able to grow vigorously in a rooting medium free of combined nitrogen (Bond, Fletcher & Ferguson, 1954; Gardner & Bond, 1957; Bond, 1958). Obviously fixation of atmospheric nitrogen is associated with the nodulated plants, and there is clear evidence that the fixation occurs in the nodules. Thus if a nodulated plant is exposed to isotopic nitrogen for a period, subsequent assay shows a relatively high concentration of combined ^{15}N in the nodules, with smaller levels in the root and shoot (Bond, 1955). If the nodules are separated from the plants before exposure to excess ^{15}N, they show ability to fix the labelled nitrogen—incidentally to a greater extent than detached legume nodules (Bond, 1957)—but the denodulated plants show none.

For the reason that so far the endophytes in these nodules have not been isolated into pure culture, it is almost impossible to raise nodulated plants of these species under aseptic conditions, with no form of life present other than the host plant and the nodule endophyte. Quispel (1954) however has come very near to achieving this in *Alnus*, and still observed fixation. I cannot see any explanation for our results other than that the fixation is carried out by a symbiotic organism within the nodules, just as in legumes.

It is with the question of the identity of the organisms within these non-legume nodules that most previous investigators of the nodules have been concerned. Many cytological observers have perceived a hyphal organism with Actinomycete characters, while others have seen no true hyphae and believe that a plasmodial organism is present; the question was discussed by Fletcher (1955). The contents of the nodule cells are very congested, and it is not surprising that opinions on their nature should be discrepant.

The significance to ecology and forestry of the almost newly discovered nitrogen fixation occurring in these non-legumes has been discussed elsewhere (Bond, 1958), and the thesis has been advanced that these genera have been and still are important sources of combined nitrogen for plants in general, especially perhaps in the colder regions of the world. Any consideration of the geochemistry of nitrogen in which these plants are not mentioned is in my opinion incomplete.

There are also nodular structures on the roots of certain Gymnosperms for which a function of nitrogen fixation has been suggested. All genera of the Podocarpaceae—an important southern hemisphere group including over 100 species, some of them valuable timber trees—bear on their roots very large numbers of nodular structures tenanted by a micro-organism which a majority of observers consider

to be a hyphal fungus. Small-scale sand cultures set up by Nobbe & Hiltner were considered by them to point to the occurrence of fixation in *Podocarpus* nodules, but my own observations do not bear this out. Nodulated plants grown for the last fifteen months in sand culture without combined nitrogen are showing increasing signs of a deficiency of that element, while numerous samples of nodulated roots exposed to excess ^{15}N showed not the slightest evidence of fixation. The investigation is continuing.

Next to be considered are the so-called leaf nodules of the tropical genera *Pavetta*, *Psychotria* and *Chromelia*, belonging to the Rubiaceae. Bremekamp (1933, 1934) reported that the majority of the 343 species which he distinguished of *Pavetta* have leaf nodules, and 42 out of the 500 species of *Psychotria*. Von Faber, who called the nodule bacterium *Mycobacterium rubiacearum*, obtained evidence somewhat suggestive of fixation, but Humm (1944) disagreed, and on the basis of his own experiments concluded that the undoubted value of the nodules to the plants has a different though at present unknown explanation. My only contribution to this question is to report that a detached leaf of *Psychotria bacteriophila*, bearing some 220 nodules, showed no evidence of enrichment after 72 hours exposure to labelled nitrogen. While thinking about leaves we may also recall the finding of Ruinen (1956) that the nitrogen-fixing bacterium *Beijerinckia* (related to *Azotobacter*) can be isolated from the surface of the leaves of many trees and shrubs in Java and Sumatra. She suggested that a symbiosis might exist, with the bacteria nourished by metabolites thought to exude from the leaves, and that the luxuriance of tropical growth might be due in part to an enhancement of nitrogen supply in this way. This important suggestion awaits confirmation.

As final examples of symbioses where there is a history of suspected fixation we come to those involving blue-green Algae. The various genera of the Cycadaceae bear nodular structures on their roots resembling superficially those of *Alnus* or *Ceanothus*. A blue-green Alga, variously identified as a *Nostoc* or an *Anabaena*, occupies a particular zone in the nodules. A few workers have isolated blue-greens from the nodules and have tested the pure cultures for nitrogen-fixing ability, with varying results. Last summer I exposed to labelled nitrogen several samples of detached nodules of *Ceratozamia* and *Encephalartos*, kindly made available by the Curator of the Glasgow Botanic Gardens. Clear evidence of strong fixation was obtained, while roots alone without nodules showed no fixation. Naturally one wonders whether the Cycad-type plants so prevalent in the Jurassic and Cretaceous periods augmented their nitrogen supply in this manner and were thus source plants of fixed nitrogen for life in general, at a time prior to the appearance of the Angiospermous nodule plants.

Saubert (1947) has provided good evidence of the ability of the fern *Azolla*, when containing *Anabaena* in its leaf cavities, to grow freely in culture solution free of combined nitrogen, indicative of the occurrence of fixation; it is of interest that the fossil record shows that *Azolla* was widespread in Europe during interglacial periods. Certain liverworts, e.g. *Blasia*, exhibit rather similar cavities containing *Nostoc*, and in this case there is isotopic evidence of the occurrence of fixation (Bond & Scott, 1955).

Some 8 per cent of all lichen species contain an algal symbiont of the blue-green type, most commonly a *Nostoc*. My colleague Dr. G. D. Scott has tested field material of various lichen thalli for fixation by exposing samples to excess ^{15}N, and in addition to his published data (see Bond & Scott, *loc. cit.*) has made unpublished ones available to me. The three lichens to be tested containing blue-green Algae—*Peltigera*, *Collema*, *Leptogium*—all showed clear evidence of fixation, while five lichens—including *Cladonia* and *Parmelia*—with green Algae showed no, or only a trace of, fixation. It is reasonable to attribute the fixation in the first examples to the blue-green Alga.

In conclusion it may be noted that, in the past, the concentration of nitrogen fixation studies at agricultural institutions has resulted in a neglect of plants which were unsuited for exploitation in agriculture. The new information presented in this paper, though not entirely bereft of the possibilities of practical exploitation, refers essentially to plants of regions not upset by agricultural operations, and helps to elucidate the sources of nitrogen for life in such regions in past and present eras.

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BIOCHEMICAL ASPECTS OF NITROGEN FIXATION

By G. Leaf

The investigation of a biochemical problem of this type is usually resolved into searching for the answers to two questions—What happens? and How does it happen? In the case of nitrogen fixation we are still seeking an answer to the first question—i.e. what are the chemical changes undergone by the atoms of elementary nitrogen during its conversion to the organic nitrogen compounds of the organism? As the first step towards answering this question, it would be desirable to define the limits of the fixation process. We can anticipate, from general biochemical experience, that the conversion of elementary nitrogen into protoplasmic nitrogen will probably occur in a sequence of steps and at some stage the pathway will merge with that used for the assimilation of combined nitrogen—for all nitrogen-fixing organisms can use certain forms of combined nitrogen if such are provided. Thus to determine where fixation ends, we must define the point at which these pathways converge, i.e. the first intermediate stage which is common to the assimilation of combined and elementary nitrogen. Until very recently, as little was known about the assimilation of combined nitrogen as about fixation, so the search centred round the product of fixation which first combines with carbon compounds to yield organic nitrogen compounds. For this role the most serious consideration has been given to ammonia and hydroxylamine.

The excretion of traces of hydroxylamine, NH_2OH, by the nitrogen-fixing bacterium, *Azotobacter*, was observed by Blom in 1931. This finding was subsequently confirmed by Virtanen and his colleagues who also claimed to find this substance among the nitrogenous substances which may sometimes be excreted by the root nodules of leguminous plants (Virtanen, 1947, 1948). Together with

hydroxylamine they also identified the oxime of oxalacetic acid and aspartic acid but no glutamic acid. They therefore proposed the following sequence of reactions for the entry of the fixed nitrogen into organic combination:

$$N_2 \rightarrow\rightarrow\rightarrow NH_2OH + \underset{\underset{CH_2COOH}{|}}{CO.COOH} \rightarrow \underset{\underset{CH_2COOH}{|}}{HON{=}C.COOH} \quad (1)$$

oxalacetic acid — oxime

$$\longrightarrow \underset{\underset{CH_2COOH}{|}}{H_2N{-}CH.COOH} \longrightarrow \text{other amino acids}$$

aspartic acid

As indicated by Dr. Fowden (below), aspartic acid is active in transamination and could readily pass on its nitrogen by this mechanism to form other amino-acids. Attempts by other investigators to confirm these findings were unsuccessful and subsequently Virtanen found glutamic acid among the nodular excretion products. As will be shown later, this amino-acid was more likely to be formed from ammonia than from hydroxylamine and this led Virtanen to suggest that though hydroxylamine is formed during fixation it may normally be reduced to ammonia before assimilation of its nitrogen.

It has long been known that nitrogen-fixing organisms excrete ammonia into the surrounding medium but, as ammonia is produced during the breakdown of organic matter, there has always been doubt as to whether this ammonia represented the precursor of organically combined nitrogen or was the product of its decay, as in (2).

$$N_2 \rightarrow\rightarrow\rightarrow\rightarrow NH_3 \rightarrow \text{organic–N} \rightarrow NH_3 \quad (2)$$

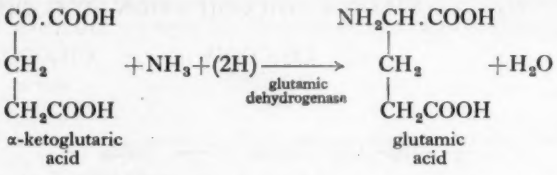
The problem of distinguishing between these two potential sources of ammonia has not so far been satisfactorily solved but a good deal of evidence that ammonia is the precursor of organic nitrogen has nevertheless been obtained. Much of this evidence derives from the use of the isotope of nitrogen, ^{15}N, as a tracer—a method introduced into this field by Wilson and Burris. Dr. Bond has described how this method may be used to detect fixation. For the investigation of the metabolic fate of the nitrogen fixed, the method involves exposure of the organism, for a short time, to an atmosphere containing an abnormally high proportion of the heavy isotope. The nitrogenous constituents of the organism are then separated and the ratios of ^{15}N to ^{14}N in these compounds are determined by means of the mass spectrometer. Comparison of these ratios yields information about the metabolic relationships between the compounds, for in a series of compounds formed by a sequence of reactions, e.g.

$$^{15}N_2 \rightarrow A \rightarrow B \rightarrow C$$

the relative abundance of ^{15}N in the compounds will decline as their relationship to the source of isotope becomes more remote, i.e. from A to C. In so far as the living organism does not distinguish between the two isotopes, such information may be obtained under conditions which can be regarded as quite normal.

Wilson and Burris performed a number of such experiments with bacteria, algae and legume root nodules (Wilson, 1952). In no case was the highest abundance of ^{15}N found in ammonia but in all cases the distribution of ^{15}N among the amino-acids was similar to that obtained after feeding $^{15}NH_3$. The greatest abundance of the isotope was found in glutamic acid and rather less in aspartic acid and alanine and still less in other amino-acids. A similar distribution of isotope is found in all

organisms supplied with $^{15}NH_3$ and it derives from the fact that whereas glutamic acid can be formed directly from ammonia by action of the enzyme glutamic dehydrogenase (equation (3))



(3)

other amino-acids obtain their nitrogen from glutamic acid by transamination, as indicated by Dr. Fowden. The apparent contradiction in the results of these experiments of Wilson and Burris was resolved by assuming that the extracted ammonia was derived from two or more 'pools' and that only one of these pools was involved directly in the fixation mechanism. During extraction, the high enrichment of this 'active pool' would be masked by dilution from the inert pools. This explanation in itself was plausible but it appeared surprising that this situation only affected ammonia and not other constituents. Indirect experimental support for this view has however been obtained by Burris and his colleagues.

First, in similar experiments with the bacterium *Clostridium pasteurianum* the highest enrichment was found in the ammonia fraction (Zelitch, Rosenblum, Burris & Wilson, 1951). It could be argued that as this organism, being anaerobic in habit, may possess a mechanism of fixation different from the majority of nitrogen-fixing organisms which are aerobic in habit and definitely require oxygen to fix nitrogen. More recently, however, similar evidence has been obtained with the aerobe *Azotobacter vinelandii* (Allison & Burris, 1957). Using an atmosphere containing nitrogen enriched to the extent of 50 atoms per cent excess of ^{15}N, they were able to detect and measure the isotope in constituents of the medium and the soluble fraction of the cell contents after exposures as short as one minute. They found that after very short exposures the ammonia fraction showed the highest enrichment with ^{15}N. After two minutes, however, the enrichment of the ammonia remained constant at about two atoms per cent excess and thereafter was surpassed by that of glutamic acid and subsequently other constituents. These observations suggest that there is indeed more than one pool of ammonia and that the more active one becomes saturated with ^{15}N after some two minutes. On extraction, however, this active pool is diluted with some twenty-five times as much inert ammonia. The enrichment of the extracted ammonia therefore becomes stabilised at one twenty-fifth of the expected saturation value (50 atoms per cent excess).

As described in the preceding paper, Bond has shown that there are a number of plants, in addition to legumes, which have the property of fixing nitrogen by virtue of a symbiosis between the plant and a micro-organism inhabiting the root nodules. The nature of the micro-organisms has not been determined but they appear to be different from the rhizobia found in leguminous nodules. It seemed possible, therefore, that the mechanism of fixation may also differ from those of the systems studied hitherto and it is by discovery and examination of such differences that we gain perspective on biochemical mechanisms. Experiments were therefore carried out to determine the fate of nitrogen fixed by nodules of alder (*Alnus glutinosa*) and bog myrtle (*Myrica gale*) (Leaf, Gardner & Bond, 1958, 1959).

The data obtained with alder nodules are given in Table I. A large proportion of the soluble nitrogen of alder nodules is contributed by citrulline and it is notable that after exposure to $^{15}N_2$ the highest abundance of ^{15}N was found in the carbamyl group of this amino acid; not in ammonia or even glutamic acid. To appreciate the significance of this, it is only necessary to note that the synthesis of

TABLE I

Distribution of ^{15}N in alder nodules supplied with $^{15}N_2$ for 30 minutes

	Mg. N per 100 g. fresh weight of nodule	Atom per cent excess ^{15}N
Aspartic acid	0·7	0·157
Glutamic acid	2·3	0·250
Citrulline	21·0	0·076 (ornithine-N) 0·390 (carbamyl-N)
γ-aminobutyric acid	0·9	0·093
Arginine	3·5	0·012
Ammonia	2·5	0·187

citrulline almost certainly occurs by the reaction of carbon dioxide and ammonia with the amino-acid, ornithine (Ratner, 1956):—

$$\begin{array}{l} CH_2NH_2 \\ | \\ CH_2 \\ | \\ CH_2 + CO_2 + NH_3 \\ | \\ CH.NH_2 \\ | \\ COOH \\ \text{ornithine} \end{array} \quad = \quad \begin{array}{l} CH_2HNC\overset{*}{O}NH_2 \\ | \\ CH_2 \\ | \\ CH_2 + H_2O \\ | \\ CH.NH_2 \\ | \\ COOH \\ \text{citrulline} \end{array} \qquad (4)$$

The carbamyl nitrogen (marked with an asterisk) is therefore derived directly from free ammonia.

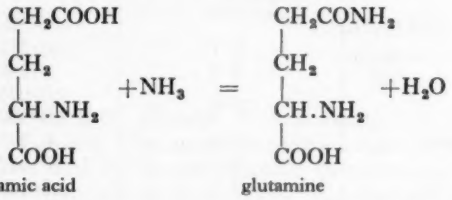
The nodules of *Myrica* do not contain citrulline but contain the amino-acid amides, glutamine and asparagine, the latter being the predominant nitrogenous constituent of the soluble fraction of the nodule (Table II). In this respect they

TABLE II

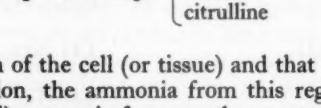
Distribution of ^{15}N in Myrica nodules supplied with $^{15}N_2$ for 60 minutes

	Mg. N per 100 g. fresh weight of nodules	Atom per cent excess ^{15}N
Aspartic acid	3·5	0·427
Glutamic acid	6·4	0·602
Asparagine	27·5	0·506 (amide-N) 0·149 (amino-N)
Glutamine	2·8	1·450 (amide-N) 0·460 (amino-N)
Glycine	0·6	0·054
Alanine	1·5	0·810
Tryptophan	3·0	0·359
Arginine	3·9	0·002
Ammonia	5·0	0·736

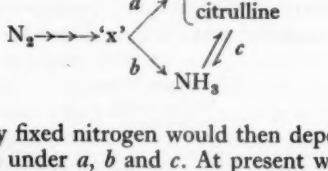
are more like legume nodules than those of alder. In *Myrica* nodules which had been exposed to $^{15}N_2$ the highest abundance of isotope was found in the amide group of glutamine and next highest in the amide group of asparagine and the amino group of free glutamic acid which were more or less equal. The available evidence suggests that these amides are formed by the direct condensation of the amino-acid with free ammonia, e.g.:



Thus in both types of nodule the greatest abundance of the isotope is found in chemical groups derived directly from ammonia rather than in the free ammonia fraction. This general finding may be explained in every case by the existence of a situation similar to that which appears to occur in *Azotobacter*, i.e. that the sequence of reactions



occurs in a special region of the cell (or tissue) and that on destruction of the cell structure during extraction, the ammonia from this region is diluted with inert (and therefore unlabelled) ammonia from another part of the cell which does not contain much glutamic acid, etc. However, as there is direct evidence in support of this thesis only in the case of *Azotobacter*, other explanations may be offered. An alternative explanation is that the immediate product of fixation is not free ammonia but some substance which is capable of forming ammonia or of passing its nitrogen directly to substances metabolically close to ammonia.



The distribution of newly fixed nitrogen would then depend on the relative rates of the reactions included under *a*, *b* and *c*. At present we know of no substance which would have the properties required of 'x' but a recent observation by Bach (1957) may be of interest in this connection. After exposure of *Azotobacter* to $^{15}N_2$, he found the highest abundance of the heavy isotope in an organic fraction which he therefore suggested may contain a compound which precedes ammonia in the fixation mechanism. In support of this he showed that the relative enrichment of the fraction was greater when the organisms were grown on $^{15}N_2$ than on $^{15}NH_3$. This finding, at first sight, appears to conflict with the mechanism (6) proposed above for *Azotobacter*. This is not really so, as mechanism (6) may occur as a special case of (7), where reactions *b* and *c* are much more rapid than *a*.

To distinguish between these mechanisms we require to know more about the intermediate stages in the fixation process, between N_2 and NH_3, but here we are

at present dependent largely on speculation. Virtanen, Burris and others have postulated the following possible pathways (see Burris, 1956):

$$N_2 \xrightarrow{O} N_2O \xrightarrow{H_2O} \begin{matrix} NOH \\ \| \\ NOH \end{matrix} \xrightarrow{4H} 2NH_2OH \xrightarrow{4H} 2NH_3 \qquad (8)$$

$$N_2 \xrightarrow{2H} (NH{=}NH) \xrightarrow{2H_2O} 2NH_2OH \xrightarrow{4H} 2NH_3 \qquad (9)$$

$$N_2 \xrightarrow{2H} (NH{=}NH) \xrightarrow{2H} NH_2NH_2 \xrightarrow{2H} 2NH_3 \qquad (10)$$

All three must be considered, as we have no evidence as to whether the first step involves oxidation (8) or reduction (9 and 10). Attempts have been made therefore to determine whether substances represented in these schemes behave in a manner typical of intermediates. They should be able to support growth in absence of other sources of nitrogen and also inhibit reactions leading to their formation. Nitrous oxide (N_2O) inhibits nitrogen fixation in *Azotobacter* but is only used at 5 per cent of the rate of elementary nitrogen (Burris, 1956). Hyponitrous acid was found by Roberts and Wilson (1954) to be a general poison. This evidence militates against the oxidative pathway (8). Hydroxylamine and hydrazine ($NH_2.NH_2$) are also highly poisonous in all but the lowest concentrations (10^{-5}M). When supplied in sufficiently dilute solution, however, they appear to be used by *Azotobacter*. Bach (1957) confirmed this for hydrazine with a sample labelled with ^{15}N, but none of the isotope found its way into glutamic acid and this seems incompatible with its being an intermediate in fixation.

The occurrence of hydroxylamine as an intermediate appears to be much more likely. As mentioned earlier, it is claimed that some nitrogen-fixing organisms excrete traces of this substance. There is also evidence of its formation in many plants and micro-organisms, for it is thought to be an intermediate in the reduction of nitrate to ammonia (Nason, 1956). Unfortunately attempts to study the effects and fate of hydroxylamine added to the intact organism are useless as this substance is very unstable in dilute solution and is readily converted to ammonia. This illustrates difficulties inherent in this type of experiment. A negative result may be due to failure of the substance to reach the appropriate part of the interior of the cell in the required concentration: a positive result may merely mean that the added substance can be converted to the true intermediate.

These, and other difficulties besetting the path of the investigator in this field, can probably only be overcome by studying the process in systems less complex than intact cells. Unfortunately no consistent success has attended attempts to bring about fixation of nitrogen by cell-free preparations. Any damage to the physical structure of the cell abolishes its power of fixation and in the case of plant nodules even slicing, which can only damage a small proportion of the cells, reduces their power of fixation disproportionately. We do not know why this is so, but the secret, when it is found, may provide the key to further progress in the field.

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THE INCORPORATION OF INORGANIC NITROGEN COMPOUNDS INTO AMINO-ACIDS AND PROTEINS OF PLANTS

By L. Fowden

The synthesis of proteins is the ultimate stage of nitrogen metabolism in plants. It is unnecessary to stress the importance of this process when it is realised that protein molecules form the basis of enzymes, participate as an integral part of the plasma membrane of cells, and confer on protoplasm a loose structure which enables the cell to maintain a definite degree of organisation so necessary for its proper functioning. But before the synthesis of proteins can begin nitrogen must be introduced into about twenty amino-acids and amino-acid amides that form the building blocks of the protein molecules.

As indicated by Dr. Bond, in a majority of plants the nitrogen to be used in protein synthesis must be available in the environment in a combined form. In most soils nitrate is the most abundant form of available nitrogen; ammonium salts are also important. Though there is some ability to utilise organic forms of nitrogen, higher plants tend to use nitrate or ammonium-nitrogen in preference to that which is organically bound (Ghosh & Burris, 1950).

The use of ^{15}N has allowed the pathway of inorganic nitrogen incorporation into organic compounds to be studied. The results of Mendel and Vissar (1951) show that irrespective of whether ^{15}N atoms are supplied to tomato plants in the form of ammonium salts or as nitrate, the sequence in which these atoms enter various organic compounds such as amides, aspartic and glutamic acids and protein remains the same (see Table I). The final reaction pathways responsible for the introduction of ^{15}N into organic compounds would then seem to be the same for both forms of nitrogen supplied. Since ammonium-nitrogen enters the amino-acids and protein far more rapidly than nitrate-nitrogen, the former must be metabolically more closely related to the amino-acids. Other evidence indicates that nitrate and indeed all forms of inorganic nitrogen must first be converted to ammonium-nitrogen before they can be utilised for amino-acid synthesis.

TABLE I

A comparison of the distribution of ^{15}N in tomato plants given labelled ammonium salts or nitrate, results expressed in atom per cent excess ^{15}N (after Mendel & Vissar, 1951)

Fraction	$^{15}NH_4^+$ fed for 8 hr.			$^{15}NO_3^-$ fed for 8 hr.		
	Root	Stem	Leaf	Root	Stem	Leaf
Ammonia	0·78	0·33	0·22	0·13	0·24	0·37
Amide	0·67	0·23	0·17	0·13	0·20	0·25
Glutamic acid	0·35	0·12	0·09	0·04	0·03	0·06
Aspartic acid	0·26	—	0·07	0·03	0·03	0·04
Protein	0·06	0·02	0·02	0·01	0·02	0·01

The following pathway for the reduction of nitrate to ammonia by plants and micro-organisms remained a working hypothesis for several decades:

$$\underset{\text{nitrate}}{HNO_3} \xrightarrow{+2H} \underset{\text{nitrite}}{HNO_2} \xrightarrow{+2H} \underset{\text{hyponitrite}}{[HNO]} \xrightarrow{+2H} \underset{\text{hydroxylamine}}{H_2NOH} \xrightarrow{+2H} \underset{\text{ammonia}}{NH_3}$$

Mainly through the work of Nicholas's group at Long Ashton and that of Evans and Nason in America, recently each step in this sequence has been studied separately in micro-organisms such as *Neurospora* and *Aspergillus*, and there seems good reason to believe that eventually a similar complete pathway will be found for higher plants. The production of each intermediate involves a transfer of two electrons from a suitable donor molecule (reduced di- or triphosphopyridine-nucleotide, substances which are usually referred to as DPN and TPN respectively) to the appropriate substrate. The enzymes responsible for the catalysis of these reductions are dependent upon small amounts of certain heavy metals for optimum activity (see Table II). One or more of these metals, together with flavin-adenine-dinucleotide (FAD) appears to be associated with the prosthetic group of each

TABLE II

The co-factors required in the reduction of nitrate to ammonia (after Nicholas, 1957)

Reduction sequence	HNO_3	$\longrightarrow HNO_2 \longrightarrow$	$[HNO] \longrightarrow$	$H_2NOH \longrightarrow$	NH_3
Oxidation state of N	+5	+3	+1	−1	−3
Metal requirement	Mo	Fe Cu	Fe Cu		Mn
TPN or DPN	+	+	+		+
FAD	+	+	+		+

enzyme. The process of nitrate reduction then provides a nice example at the biochemical level of why certain metals are required in trace amounts for the normal growth of plants. A definite role for the B vitamins, riboflavin and nicotinic acid, is also apparent since they form part of FAD and DPN or TPN respectively.

Although higher plants can tolerate quite high internal concentrations of nitrate, ammonia never accumulates in large amounts in a healthy plant; the high ammonia levels which may be found in senescent or excised leaves are an indication of approaching death. Once ammonia is taken up by plant roots or formed by reduction of nitrate it is quickly converted into organic nitrogen compounds. In higher plants the main ports of entry seem to be into the amino-acid, glutamic acid, or the amides, glutamine and asparagine (Table I). Work in the laboratories of Professor Yemm at Bristol confirmed that ^{15}N atoms fed to young barley plants in the form of ammonium phosphate were primarily incorporated into glutamic acid and glutamine.

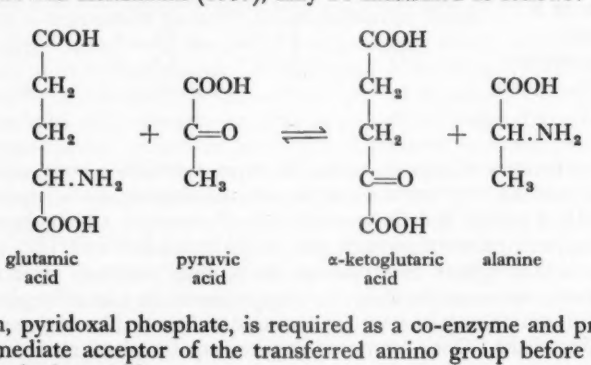
As stated by Dr. Leaf, it is generally agreed that glutamic acid arises in plants by a two-stage reaction in which glutamic dehydrogenase, an enzyme of very wide distribution in the plant kingdom, is operative. To this synthesis the respiratory processes supply not only the α-ketoglutarate but are also responsible for maintaining a continuous production of reduced DPN. Therefore although the reactions are reversible, conditions can exist in which the equilibrium is forced well in favour of glutamic acid synthesis.

Glutamine and asparagine are formed when one molecule of ammonia combines with one of glutamic and aspartic acids respectively. Energy must be supplied for amide bond formation and in the case of glutamine an associated splitting of the

energy-rich substance adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and inorganic phosphate occurs to provide this energy (Elliott, 1953). Webster and Varner (1955) have claimed that asparagine is formed by a similar mechanism.

Two other keto-acids, namely pyruvic and oxaloacetic acids, are produced during the respiratory breakdown of carbohydrate to carbon dioxide and water, and suggestions have been made that they, too, may undergo direct reductive amination by ammonia to give the amino-acids alanine and aspartic acid respectively. The supporting experimental evidence is fairly sound in regard to the amination of pyruvate in certain micro-organisms but rigid proof is still required for higher plants. In practice it is most difficult to establish that formation of alanine from pyruvate and ammonia did not in fact involve a primary production of glutamic acid followed by a transamination (see below). While mutants of certain micro-organisms have been found in which glutamic dehydrogenase or the glutamic acid transaminase are lacking (it was by using such an organism that the direct amination of pyruvate was established), higher plants lacking either of these enzymes are not known to exist.

Glutamic acid formation then remains as the only widely distributed process in plants by which the nitrogen atom of ammonia can enter directly the α-amino group of an amino-acid. How then is nitrogen introduced into the remaining amino-acids? Transamination reactions provide the present-day panacea to this problem. In these the primary product of ammonia assimilation, glutamic acid, donates its amino group to other appropriate acceptor keto-acids. This process, first described by Braunstein and Kritzmann (1937), may be illustrated as follows:



The vitamin, pyridoxal phosphate, is required as a co-enzyme and probably acts as an intermediate acceptor of the transferred amino group before it is finally passed on to the keto acid.

Transaminase enzymes have been demonstrated in seeds, roots, stems and leaves of flowering plants and in ferns, algae, fungi and bacteria. The transaminases from a single plant species have been shown to be capable of catalysing the transfer of the amino group from seventeen amino-acids to α-ketoglutarate as acceptor (Wilson, King & Burris, 1954), whilst Meister (1957) lists about sixty different transamination reactions. If transamination is to be regarded as the dominant mechanism for amino-acid synthesis it is implicit that keto-acid analogues of all protein amino-acids must be present within plants. The half-life of a keto-acid molecule in plants seems to be short—a matter of seconds or minutes at the most according to Millbank (1957)—and so even the common ones like α-ketoglutarate and pyruvate never attain concentrations comparable with those of the other respiratory intermediates of the tricarboxylic acid cycle. Detection of keto-acids is therefore difficult and at present we cannot say with certainty that all the required acids are constituents of plants. The keto-acid analogues of aspartic acid, alanine, glycine, serine, threonine, valine and tryptophan have been demonstrated to occur

in higher plants but there seems to be no record of the ten other necessary acids, though it is possible that they are present in concentrations too low for detection by methods at present available.

The importance of glutamic acid in amino-acid metabolism is further emphasised when it is realised that proline, ornithine, citrulline and arginine can all be formed from it by well-established reaction sequences. As pointed out by Dr. Leaf, in the steps leading to citrulline and arginine additional molecules of ammonia are directly involved. Other work with micro-organisms has shown that aspartic acid, formed rapidly from glutamic acid and oxaloacetic acid by transamination, can be converted to other four-carbon amino-acids (homoserine, threonine and methionine).

The ammonia-nitrogen rapidly assimilated into glutamine and asparagine apparently cannot be utilised in the synthesis of other amino-acids unless the amide groups are first hydrolysed to regenerate ammonia. The amides have then been viewed as reserve compounds in which excess ammonia-nitrogen may be temporarily stored. Whilst attempts have been made to give them, and especially glutamine, a more positive role in protein synthesis, such concepts still require substantiation.

We have seen that ammonia-nitrogen can be assimilated rapidly into amino-acids. The requisite carbon skeletons of the amino-acids may also be elaborated rapidly and a close relationship exists between photosynthesis and amino-acid synthesis. Thus the early experiments of Calvin and co-workers on the pathway of carbon in photosynthesis showed that aspartic acid, alanine, serine and glycine had gained appreciable radioactivity only 30 seconds after $^{14}CO_2$ had been supplied to the alga *Scenedesmus*. The rapid rates of synthesis are paralleled in many cases by equally fast rates of utilisation either in the synthesis of proteins or by degradative reactions catalysed by transaminases or oxidases. Molecules of many amino-acids have then somewhat fleeting existences, and values obtained in my laboratory with the use of ^{14}C-labelled compounds indicate that the average life of an alanine molecule present in leaves is probably less than 30 minutes; even molecules of the less reactive acids probably do not have lives of more than about one day. Indeed, a dynamic state of existence is a characteristic feature of amino-acids.

Many of the problems involved in protein synthesis are still unresolved. Now, however, few people would doubt that the amino-acids are involved as direct precursors in the synthetic process. The number of free amino-acid molecules relative to those bound in proteins can be correlated with the physiological status of the plant tissue in which they occur, and tends to be very low in rapidly growing material, such as higher plant meristems and micro-organisms undergoing rapid cell division. In older tissues and storage organs, e.g. potato tuber and carrot root, the quantities of amino-acids present in the free state may exceed those bound in protein. The cells of older tissues are usually vacuolated and it is probable that most of the free amino-acids are present within the vacuoles and are not immediately concerned in protein synthesis, a process which goes on perhaps mainly within the microsomes.

The complex chemical structure of proteins necessitates that certain requirements must be satisfied by any proposed synthetic mechanism. Thus the formation of peptide bonds is an energy-requiring process and so some means of supplying this energy has to be available. It is also necessary to have a mechanism that provides for the precise ordering of individual amino-acids during condensation into a protein chain and which finally effects a folding or spiralisation of the primary condensation products to give molecules of finite molecular weight and shape. It is difficult to see how cells elaborate such unique molecules day after day without any hitch unless they use some sort of biological pattern or press. Template theories to explain protein synthesis are therefore much in vogue. Most people

assume that if patterns or templates exist they are very likely to be specific ribonucleic acid (RNA) molecules, but the idea that protein molecules may act as templates also has its supporters. Attention may be drawn to the recent paper by Zamecnik (1958) where it is proposed that amino-acids are conveyed to template RNA molecules in 'carrier' complexes in which cytoplasmic RNA is involved. Particular amino-acids can be united with the template only at certain definite positions determined by the molecular geometry and thus by the chemical structure of the template. Finally, as a result of a transfer of linkages which is pictured as running along the chain in 'zipper' fashion the amino-acids become joined together and separated from the template, and a new protein molecule peels off the template.

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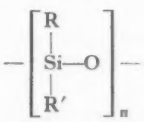
SILICONES: AN INTRODUCTION TO THEIR CHEMISTRY AND APPLICATIONS[1]

by

DR. G. G. FREEMAN [2]

SILICONES may be defined as synthetic polymeric compounds containing silicon oxygen and organic groups. They are organopolysiloxanes whose chemical and physical properties are dependent on the presence of a silicon-oxygen-silicon skeleton. They may conveniently be classified as fluids, resins and elastomers or rubbers. In general, interest in the silicones and their industrial applications are dependent upon one or other of the following characteristics: constancy of properties over a wide range of temperature, water repellency, low surface tension and anti-adhesive properties. In a sense the term silicone, first introduced by Kipping, is a misnomer since it was originally intended to describe organo-silicon compounds analogous to the ketones of organic chemistry,

whereas actually the silicones are polymeric substances with the structure



Silicon was first isolated by Berzelius in 1824 by heating potassium fluosilicate, K_2SiF_6, with potassium. From silicon by reaction with chlorine he obtained silicon tetrachloride $SiCl_4$. Ebelman treated silicon tetrachloride with ethyl alcohol and obtained ethyl silicate $Si(OC_2H_5)_4$. Wöhler in 1857 heated elemental silicon with carbon and passed hydrochloric acid gas over the mixture and obtained a liquid product boiling at 28° C. The product was trichlorosilane $SiHCl_3$ (silicochloroform). If he had used an organic chloride such as methyl chloride instead of hydrochloric acid, he would have obtained a mixture of methylchlorosilanes and anticipated by over a century one of the fundamental methods of preparing intermediates for silicones. A number of workers studied silicon chemistry during the following decades but most progress resulted from the efforts of Professor F. S. Kipping, of Nottingham University, who worked in this field from 1899 to 1944 and published fifty-four papers, mainly in the *Journal of the Chemical Society*. Kipping's interest was predominantly in the chemistry of organo-silicon compounds from the organic chemist's standpoint of isolation and characterisation of pure compounds, and he has described as 'uninviting' the unidentifiable oils and 'glue-like' substances with which he was from time to time confronted. The initial object of his work was the preparation of asymmetric compounds of tetra-substituted silicon for the study of optical rotation.

In 1904 Kipping introduced the use of the Grignard method for preparation

[1] Paper delivered to Section B (Chemistry) on August 28, 1958, at the Glasgow Meeting of the British Association.

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of the highly reactive chlorosilanes from silicon tetrachloride. This new method of synthesis was applied to the preparation of a great variety of new compounds which were isolated and identified. Nothing in Kipping's published work suggests that he foresaw any great technical usefulness for the resinous silicone polymers which he had encountered. He definitely made no attempt to develop them.

Silicon lacks the power to combine with itself and other elements to form the wide range of compounds derived from carbon. The outstanding characteristic of organo-silicon compounds is formation of macro-molecules containing chains, rings or networks of alternating oxygen and silicon atoms.

In order to understand the marked differences between the high temperature stability of silicones and of organic polymers it is necessary to consider the physical chemistry of their molecular structure. The properties of silicones are largely the properties of the polysiloxane chain influenced only slightly by the character of the side-chain groups (when these contain only a few carbon atoms). Good heat resistance is to be expected from materials whose basic structure resembles that of silica. The siloxane (silicon–oxygen) bond is partially ionic (51 per cent as compared with only 22 per cent for the corresponding carbon–oxygen bond). The bonds are thus powerful dipoles which protect the adjacent hydrocarbon groups from chemical attack and, in consequence, methyl, ethyl, phenyl and vinyl polysiloxanes are highly resistant to oxidative degradation at temperatures up to 200° C. This protective action does not extend to carbon–carbon bonds at some distance from the dipole, however, and heat stability is quickly lost as the size of the hydrocarbon group increases. The silicon–oxygen bond has good thermal stability but is relatively easily cleaved by concentrated acids and alkalis at room temperature, and dilute acids and alkalis at high temperatures.

The silicon–oxygen–silicon bond angle is large (probably 140–160°) and the siloxane link is very flexible. The covalent radius of silicon is almost twice that of carbon, and thus the organic groups attached rigidly through silicon to the flexible siloxane chain sweep out a relatively large volume of space. The close approach of adjacent molecules is therefore restricted, and intermolecular attraction is consequently weak, so that the fluids have low surface tension, low viscosity/temperature coefficients, and low freezing points. Some adverse properties also result; the low pour point, the small viscosity changes with temperature and the low intermolecular forces mean that useful thermoplastic effects are not observed in the linear polymers; and the cross-linked and condensed polymers, the rubbers and resins, have only moderate mechanical properties and swell excessively in some organic solvents.

The close-packing of organic groups round the siloxane chain gives the silicones both anti-adhesive and hydrophobic properties. These properties become more permanent after heating because the molecule then uncoils and is able to attach itself through its semi-ionic skeleton to certain types of substrate while still presenting a free surface of water-repellent and non-adhesive groups.

Manufacture

The relationship between the numerous silicone products now commercially available—all variations on a single chemical theme—is best understood by briefly considering their methods of manufacture.

There are two main commercial methods for the production of chlorosilanes, the essential intermediates for silicone manufacture: (1) The Grignard method. (2) The direct method.

The method initially used was the Grignard process but the second method is that now most widely used.

(1) In the Grignard process alkyl or aryl halides are reacted with magnesium in ether suspension to form a Grignard reagent, which is then allowed to react

with e.g., silicon tetrachloride to give a mixture of alkyl or aryl chlorosilanes, as shown below:

$$CH_3Cl + Mg \longrightarrow CH_3MgCl$$

$$CH_3MgCl + SiCl_4 \longrightarrow CH_3SiCl_3 + MgCl_2$$

$$CH_3SiCl_3 + CH_3MgCl \longrightarrow (CH_3)_2SiCl_2 + MgCl_2$$

$$(CH_3)_2SiCl_2 + CH_3MgCl \longrightarrow (CH_3)_3SiCl + MgCl_2$$

Although the reaction proceeds stepwise and produces a mixture of products, their reactivities are such as to favour a high yield of dimethyldichlorosilane. By suitable adjustment of the proportion of the reactants, any of the desired chlorosilanes can be obtained as the major product. The Grignard process is the one most suitable for the manufacture of chlorosilanes containing radicals other than methyl and phenyl, such as ethyl, vinyl, etc. Attempts to prepare these products by the direct reaction result in low yields due to break-down of carbon to carbon linkages. At first sight the Grignard process seems very attractive because of its great versatility, but this is outweighed in large-scale production by the hazards associated with the use of ether as a solvent.

(2) The direct process depends upon reaction between elemental silicon and the alkyl or aryl halide concerned to produce substituted chlorosilanes.

$$2CH_3Cl + Si \longrightarrow (CH_3)_2SiCl_2$$

The reaction is carried out in the presence of about 10 per cent of a catalyst such as copper or silver, which is intimately mixed with the powdered silicon. In the preparation of methylchlorosilanes, methyl chloride gas is passed through a vessel containing the silicon–copper mixture at 250–300° C., the volatile methylchlorosilanes are distilled off and the reaction is continued until the bulk of the silicon is consumed. Although the equation given above denotes the predominant reaction, the process is more complex than the equation indicates and results in appreciable quantities of methyltrichlorosilane (CH_3SiCl_3), trimethylchlorosilane ($(CH_3)_3SiCl$), methyldichlorosilane (CH_3HSiCl_2) and silicon tetrachloride ($SiCl_4$).

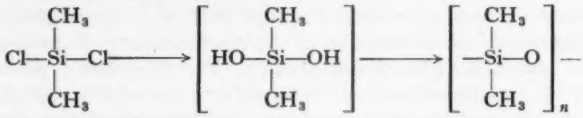
One of the major technical difficulties of the process lies in the separation of these products by distillation. A very efficient still having about 80 to 100 theoretical plates is necessary to effect a satisfactory separation. Thus the boiling points of methyltrichlorosilane (66° C.) and of dimethyldichlorosilane (70° C.) only differ by 4°. The boiling points of the products of the direct reaction and the composition of the crude mixture from the reaction of methyl chloride and silicon are given below.

Approximate Composition and Boiling Points of Direct Reaction Product

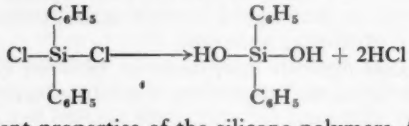
Compound	*Boiling point* (° *C.*)	*Composition of reactor crude* (%)
Dimethyldichlorosilane, $(CH_3)_2SiCl_2$	70	73·5
Methyltrichlorosilane, CH_3SiCl_3	65·7	9
Trimethylchlorosilane $(CH_3)_3SiCl$	57	6
Methyldichlorosilane, CH_3HSiCl_2	41	Small amounts
Silicon tetrachloride, $SiCl_4$	57·6	
Tetramethylsilane $(CH_3)_4Si$	26	
High boiling residue	—	
Trichlorosilane, $HSiCl_3$	32	—

Properties of Chlorosilanes

Chlorosilanes are very reactive, volatile, inflammable liquids. Their reactivity towards water, alcohols and ammonia closely resembles that of acyl chlorides such as acetyl chloride. They are very corrosive to metals. On account of their instability in the presence of water and inflammability, they have few direct industrial applications. Their main importance lies in their use as intermediates in silicone manufacture. Hydrolysis of methylchlorosilanes leads in one step to silicone polymers or cyclic compounds, since the silanols, formed as intermediates, are too unstable to be isolated under the conditions of the reaction:



Hydrolysis of diphenyldichlorosilane, on the other hand, leads to formation of diphenylsilane diol as a crystalline solid, m.p. 148° C.



The water-repellent properties of the silicone polymers, formed on hydrolysis of methylchlorosilanes, can be demonstrated by exposure, to their vapours, of: (*a*) cotton wool, (*b*) glass ampoules, and (*c*) filter paper. The water-repellency of treated filter paper may be demonstrated by separation of a mixture of water and carbon tetrachloride.

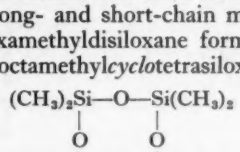
Hydrolysis of dimethyldichlorosilane yields a mixture of short-chain linear polymers and cyclic compounds of low molecular weight, in which the tetramer, octamethyl*cyclo*tetrasiloxane predominates. Hydrolysis of trimethylchlorosilane gives as the sole product the dimer, hexamethyldisiloxane.

Hydrolysis of methyltrichlorosilane (tri-functional monomer) gives a three-dimensional, highly cross-linked polymer.

The chlorosilanes are the starting points for preparation of silicone fluids, resins and rubbers, which are described below.

Fluids

Dimethyl silicone fluids are prepared from a blend of dimethyldichlorosilane and trimethylchlorosilane, the latter acting as a chain-stopper in the polymer. In preparation of polymers of high molecular weight a very small proportion of 'mono' is required in the blend, but for polymers of lower molecular weight and shorter chain length a correspondingly larger proportion of 'mono' is used. The desired blend of chlorosilanes is run into a vessel containing a large excess of water. Hydrolysis of the chlorosilanes is very rapid and is accompanied by evolution of heat and simultaneously condensation of the intermediate silanols takes place. After hydrolysis the product is separated from the aqueous layer containing hydrochloric acid and washed free from acid. At this stage the oily product consists of a mixture of long- and short-chain molecules as well as cyclic compounds, for example, hexamethyldisiloxane formed from trimethylchlorosilane, $(CH_3)_3SiOSi(CH_3)_3$, and octamethyl*cyclo*tetrasiloxane (methyltetramer),



the latter predominating in the mixture. In order to give a more even molecular distribution the fluid is then submitted to what is known as an 'equilibration' process. This is brought about by heating the mixture of polymers with an equilibration catalyst such as aqueous sulphuric acid, ferric chloride or potassium hydroxide. In practice sulphuric acid is normally used for this purpose. In this process rearrangement of the molecules takes place in which the cyclic compounds are split to give linear molecules, large molecules are broken down into shorter ones and small molecules are polymerised into larger ones. In effect, the process produces a fluid with a more normal or homogeneous distribution of molecular weights. After equilibration the fluid is decanted from the aqueous acid layer, neutralised and dried. Finally, the fluid is heated under reduced pressure to distil off volatile components of low molecular weight.

Silicone fluids are marketed under a particular viscosity label and the following are approximate molecular weights of some of the lower viscosity fluids.

Viscosity (*centistokes*)	*Average molecular weight*
50	3,700
100	6,700
300	11,300
500	19,000
1,000	26,400

Other fluids consisting of repeating units in which the substituent groups on the silicon atoms are (*a*) both methyl and phenyl radicals, and (*b*) the methyl radical and a hydrogen atom, have specific uses. They are prepared by methods similar to those already described for the dimethyl fluids.

Chemical Properties

Dimethylsilicone fluids are colourless, odourless, practically non-volatile and non-toxic materials, characterised by relatively high stability at high temperatures and constancy of physical properties over a wide temperature range (—70° C. to 200° C.). They are stable for long periods when heated in contact with air at 150° C. At 200° C. they are stable in the absence of air. In contact with air at 250° C. there is progressive increase in viscosity until after about 48 hours, when the fluid solidifies to an irreversible gel. This gelling can be delayed by addition of a suitable anti-oxidant. Silicone fluids are inert to many chemical reagents, such as 3 per cent hydrogen peroxide, fatty acids, sulphur dioxide, phenols, ammonium hydroxide, petroleum hydrocarbons and dilute aqueous solutions of mineral acids. They are unstable towards concentrated mineral acids.

The influence of temperature on the viscosity of dimethylsilicone fluids is surprisingly small. For example, the viscosities at 30° C. and 100° C. are in the ratio 5 : 2, whereas the corresponding ratio for a petroleum oil with the same viscosity at 38° C. is 10 : 1. This property is believed to be due to the ability of the molecule to form a helix (or coil), which uncoils with rise of temperature. This in turn depends upon the large size of the silicon atom (relative to carbon), the large bond angle with oxygen and the ionic character of the siloxane bond, which permit great freedom of rotation and give a very flexible molecule. When the temperature is raised the molecule uncoils to some extent and the straightened molecule offers a greater resistance to motion, which tends to counterbalance the decreased viscosity due to increased thermal agitation.

The difference in rate of change of viscosity with temperature is shown in the table below, which is a comparison between a silicone fluid with a viscosity

of 100 centistokes at 38° C. and a petroleum oil of the same viscosity at that temperature.

Temperature (°F.)	*Viscosity (centistokes)*	
	Silicone fluid	*Petroleum oil*
210	40	10·8
100	100	100
0	350	11,000
−35	660	230,000
−70	1,560	—

Industrial Applications

Some of the more important industrial applications of silicone fluids are briefly considered below:—

(1) Polishes

The use of silicone fluids as additives for car and furniture polishes constitutes the biggest usage of the fluids and is the one most familiar to the general public. Polishes of this type are formulated either as aqueous emulsions or solutions in an organic solvent; in both cases the polish consists essentially of a mixture of waxes containing about 2–4 per cent of a dimethylsilicone fluid. The popularity of the silicone-containing car polishes depends upon the lubricant property of the silicone between the planes of the wax crystals, thus facilitating the formation of a uniform thin film of wax. It is estimated that the time and labour of polishing a car with silicone polish is only one-quarter to one-half that required in using a good wax polish. In other words, the use of silicones in polishes depends primarily on the 'ease of rub-out' which they impart.

Some difficulties occurred in the past when cars which had been polished with silicone-containing polish were resprayed. This can now be readily overcome by thorough cleaning of the surface with a suitable solvent.

(2) Antifoam

Silicone fluids (in the form of aqueous emulsions) are used as antifoaming agents. The quantity of silicone required is only of the order of 50 p.p.m. Silicones have proved satisfactory in overcoming foaming troubles which have arisen in a number of sewage works owing to the domestic and industrial use of detergents and have also been used in overcoming foaming in hank dyeing of textiles. Other applications include yeast manufacture and production of antibiotics by fermentation.

(3) Release agents

In the fabrication of plastic articles, the moulding of rubber and casting of metals, the release of the finished products from the mould presents a constant problem. This is normally solved by the use of a suitable dressing on the surface of the mould to prevent sticking. The substance used for this purpose is known as a mould release agent. Traditional materials used for this purpose include oils and greases, and solids such as mica, talc or soap. The organic materials hitherto employed have the disadvantage of slowly decomposing at the moulding temperature with the deposition of carbon and other fission products on the surface of the

mould. When this occurs to a marked degree, the process must be arrested and the mould removed for cleaning. With their high stability and good release properties dimethylsilicone fluids are particularly suitable for this purpose.

A typical example is the use of emulsions of silicone fluids for release of rubber tyres from the moulds. Spraying of the moulds with the emulsion leads to the production of a very adherent silicone film on the metal surfaces so that only a small further application is required between mouldings to give easy release and good surface finish. The use of silicone fluids for this purpose is now well established in the North American and British tyre industries.

(4) Hydraulic fluids, lubricants, etc.

As described above, silicone fluids have the remarkable property of undergoing a very small viscosity change with change in temperature in the range −70° to +250° C. This and their other properties make them suitable for use as hydraulic fluids and as lubricants where large temperature fluctuations are expected. For example, an aircraft may take off from its base at an air temperature of over 100° F. (38° C.) and can meet a temperature of −100° F. (−73° C.) at 50,000 ft. directly overhead. In general, the useful temperature span and maximum working temperature of silicone lubricants increase with increasing ratio of phenyl/methyl groups in the polymer, but the viscosity temperature coefficient also increases as the proportion of phenyl groups is increased. In applications dependent upon rolling action such as ball and roller bearings, silicone fluids and greases have proved successful, but their use as boundary lubricants between two steel surfaces is poor. This property can be improved by incorporation in the silicone polymer of halogen-substituted phenyl groups.

(5) Paints additives

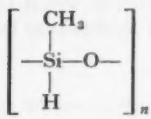
The addition of a small quantity of a low viscosity dimethylsilicone fluid to protective and decorative finishes for wood and metals assists grinding and dispersion of pigments, inhibits their flotation and promotes retention of a high gloss. In dipping applications the addition of silicone to the paint eliminates flow lines and 'silking', and in stoved finishes the additive minimises 'orange peel' (a characteristic mottled surface) and other minor defects which occur in technical scale operations. In general, the quantity of silicone fluid required for this purpose ranges from 1 to 50,000 p.p.m. The optimal amount required in any particular application should be determined by trial since excessive addition of silicone leads to serious troubles such as 'cissing'.

(6) Water repellency

Textiles. Another field of application for silicone fluids which is becoming increasingly important is as a water-repellent finish for a wide range of textiles including synthetic fibres such as nylon, 'Terylene' and 'Orlon'; the regenerated fibres—cellulose acetate and viscose rayon, as well as cotton and wool. The silicone polymer is applied either in the form of an aqueous emulsion or a solution in an organic solvent containing a suitable catalyst, such as zirconium oxychloride or an organic salt of tin, which is padded on to the fabric, dried and cured by heating at 150° C. for a few minutes. The silicone content of the liquor is adjusted so that the uptake of the cloth is about 2 per cent of siloxane. In addition to their water-repellent properties, the silicone finishes confer excellent resistance to water-borne stains and also in the case of cellulose acetate rayon and acetate-viscose rayon, improved wrinkle recovery, abrasion resistance and 'sewability' are obtained. The silicone finish is resistant to laundering and dry-cleaning.

The initial attempts to produce a permanent silicone finish on cloth starting with chain-stopped dimethylsilicone fluids were unsuccessful owing to the inert

nature of these fluids. Similarly, the use of completely polymerised resins was unsatisfactory owing to their brittle properties which cause them to break down in wear. The problem has been overcome (*a*) by use of a zirconium mordant in conjunction with a dimethylsilicone fluid in such a way that the silicone is securely anchored to the textile; and (*b*) polymers containing a large proportion of reactive hydrogen atoms built up from methyldichlorosilane (CH_3SiHCl_2) such that the repeating unit in the polymer is



Method (*b*) has been accepted by textile finishers much more readily than (*a*).

It is not yet known with certainty whether the silicone polymer is chemically combined with the textile fibre. In the case of cellulose acetate rayon treated with a type (*b*) polymer, Fortess was able to dissolve out the cellulose acetate by means of acetone and recover 'ghosts' of the silicone polymer which appeared to surround the fibres like a shell. This suggests that there is, in fact, no chemical combination.

Paper and leather. In addition to textiles, silicones can also be used for rendering leather water-repellent. In the case of paper, immersion in a silicone emulsion or solvent solution containing a catalyst, followed by heating at 80° C. for two minutes, produces an excellent anti-adhesive finish which has also some slight water-repellent properties. As in the case of textiles, a polymer containing active hydrogen atoms is used for paper treatment.

(7) Silicones in glass technology

A tenaciously adherent film of silicone may be applied to glassware by means of exposure to methylchlorosilane vapours, by immersion in a fluid containing partially hydrolysed dimethyldichlorosilane, or by treatment with a solution of dimethylsilicone fluid in an organic solvent.

Similarly, a dilute aqueous emulsion of a silicone fluid may be applied to glass vessels during their passage through the annealing lehr to produce a microscopically thin protective film of silicone. This is claimed to result in a tenfold reduction in breakages taking place in filling machinery and in transport.

Resins

Silicone resins in common with corresponding organic polymers are characterised by their three-dimensional branched-chain structures. A wide variety of silicone resins is available commercially. As a class, their heat stability, water repellency, electrical properties and resistance to many chemicals are outstanding. The film-forming properties of silicone resins are inferior to those of organic resins but work is actively in progress on the improvement of these defects.

The resins are normally prepared by hydrolysis of mixtures of di- and tri-functional alkyl and aryl chlorosilanes. The chosen chlorosilane blend is hydrolysed with water and the process may conveniently be carried out in the presence of an organic solvent to dissolve the resinous product. After hydrolysis the resin is washed to remove acid and the volatile components are evaporated off *in vacuo*. The product is then dissolved in a suitable solvent and 'bodied' by heating in the presence of a catalyst. Non-polar, water immiscible solvents such as aromatic, higher boiling aliphatic and chlorinated compounds are suitable as solvents for silicone resins.

Silicone polymers have a considerable tendency to link internally, forming ring structures rather than branched or cross-linked polymeric chains. This means that

Fig. 1.—Processing in hank dyeing can be seriously hindered by foaming.

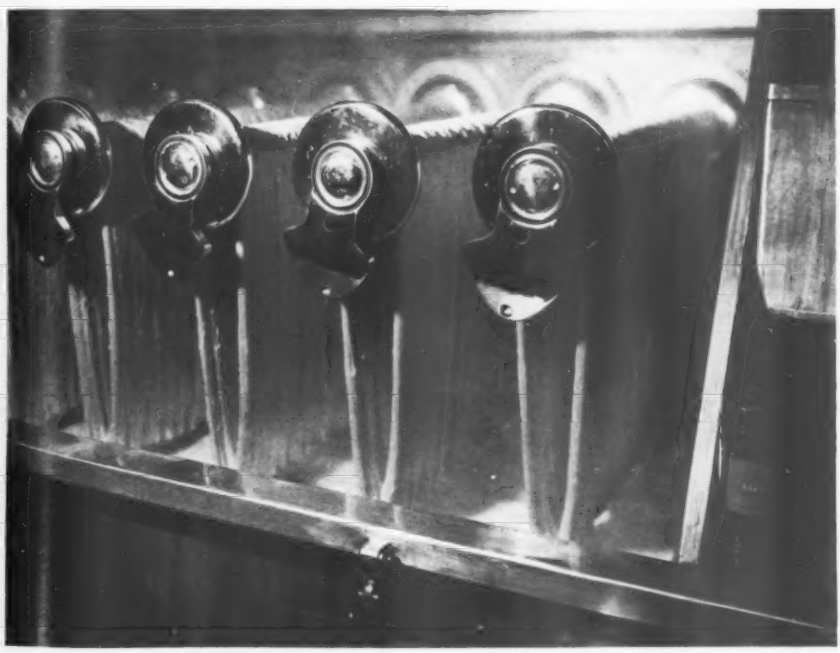


Fig. 2.—The addition of silicone anti-foam emulsion is completely effective in suppressing the foam.

[*To face p.* 101

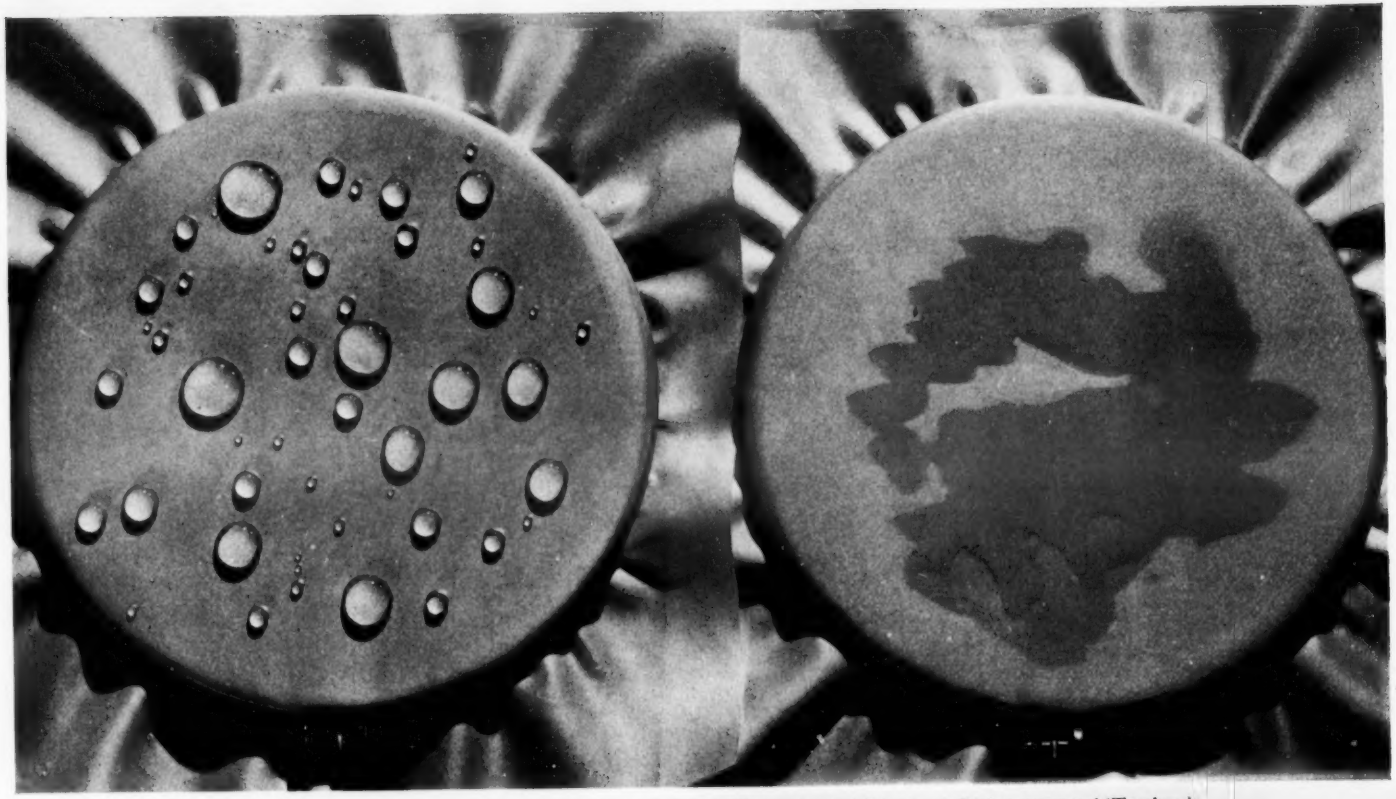


Fig. 3.—Water repellency of silicone-treated textiles: Left: Silicone treated 'Terylene'. Right: untreated 'Terylene'.

Fig. 3.—Water repellency of silicone-treated textiles: Left: Silicone treated 'Terylene'. Right: untreated 'Terylene'.

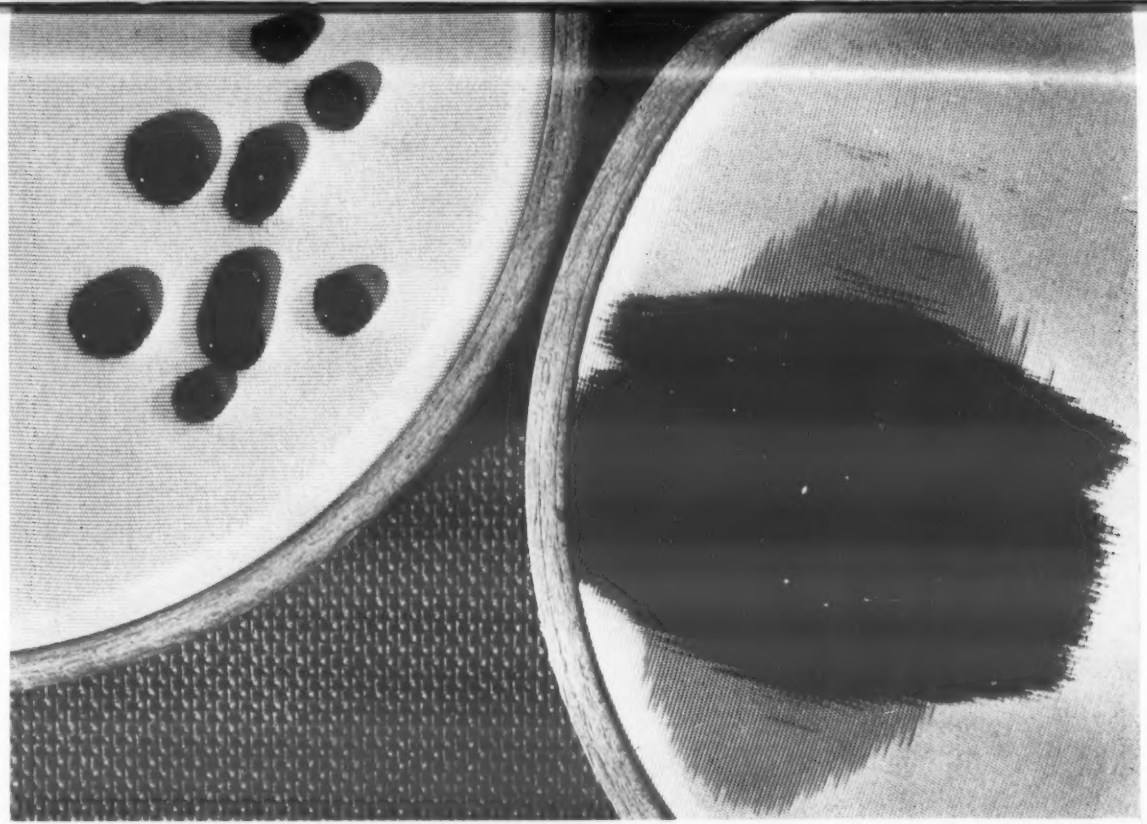


Fig. 4.—In addition to water repellency silicones endow textiles with resistance to water borne stains. Left: Ink on silicone-treated rayon. Right: Ink on untreated acetate rayon.

Fig 5. Top: the effect of exposure to ozone of (left to right) Neoprene, natural and silicone rubbers. The corresponding

their preparation requires considerably higher percentages of trifunctional units than are necessary to achieve comparable properties in the organic polymer field. Where R is an organic group, the R/Si ratio should be between 1·1 and 1·5 for optimal effect. Hydrolysis of pure trifunctional organosilicon compounds leads to intractable cross-linked products which are not suitable for use in the normal resins field. By proper selection of the components and methods of preparation a wide variety of polymers can be obtained.

The commercially available resins change by gradual steps from very flexible almost rubber-like materials on the one hand, to hard, brittle, glass-like polymers on the other. The molecular structure of the tri-functional resin polymers is only fully established when the resins are cured in their ultimate application. This reaction takes place by condensation between the hydroxyl groups of adjacent molecules to split off water and form silicon–oxygen–silicon linkages in three dimensions. Condensation is facilitated by the presence of catalysts such as trialkylamines, zinc and iron octoates and naphthenates, which are widely used in condensation reactions. Phenylsilicone resins are brittle, soluble, fusible solids, too weak for use. However, the copolymers of methyl and phenylsilicones give resins of improved flexibility, electrical properties and thermal resistance. Ethyl, propyl and butyl silicone resins have decreased heat resistance, greater softness and increased solubility as compared with the corresponding methylsilicone resins.

Electrical Properties

The use of silicone resins in electrical machines has enabled a new class of insulation to be established. Three classes of insulating materials are now recognised as follows:

Class A: cotton, paper and similar materials bonded with organic resins. Maximum operating temperature, 105° C.

Class B: asbestos, glass fibre and other inorganic materials impregnated with organic resins. Maximum operating temperature, 130° C.

Class H: asbestos, glass fibre, etc., impregnated with silicones. Maximum operating temperature, 180° C.; 200° C. in U.S. Navy specification.

Silicone insulation is recommended when the electrical equipment is subject to high operating temperatures, frequent overload conditions, or space limitation and when high moisture resistance is required. Silicone resins are used in electrical equipment as:

(1) Bonding varnishes for mica, glass fibre and asbestos. (2) Impregnating varnishes for electrical coils, motors, generators and transformers. (3) Bonding resin for laminates. (4) Coating varnish for glass cloth and sleeving.

The main advantage of Class H insulation is to permit an increased output per unit volume of motor. This is of special interest in cases where space is restricted for example, railway traction motors, aircraft and submarines.

Industrial Uses of Resins

Silicone resins are employed in a wide and increasing range of industrial applications. These include surface coatings; release agents, including release of bread from baking tins; water repellents for brickwork and masonry; and applications in the electrical industry.

(1) Surface coatings

The use of silicone resins as surface coatings depends upon their heat resistance, water repellency and resistance to chemical reagents. The film-forming properties of silicone resins are inferior to those of organic resins, and in circumstances where

Fig. 5.—Top: the effect of exposure to ozone (left to right) Neoprene, natural and silicone rubbers. The corresponding

the above properties are not required to their fullest extent, organic resins can be blended or co-polymerised with silicone with advantage. A blend of silicone and organic resins pigmented with aluminium powder can be used in applications such as metal chimneys, exhaust pipes and furnace doors involving exposure to temperatures up to 500° C. The finish should be cured at about 400° C. and during this process the resins are destroyed leaving a strongly adherent film of aluminium on the metal.

(2) Release resins

The release properties of silicone fluids which have already been described are shared by the resins. For certain applications such as release of bread from baking pans, the resins have an obvious advantage in that they can be cured on to the surface of the pan and no further treatment is necessary for 100 to 500 bakes. When properly cured, a suitable resin gives a hard, tough, semi-transparent coating, from which baked goods are readily released. The advantages of this method include economy of labour and material involved in greasing baking pans and production of a more evenly baked, cleaner loaf. The resins of this group can also be used as release agents in the rubber and plastics industries.

(3) Water-repellent treatment for brickwork and masonry

Silicones have proved valuable in providing a durable, invisible, water-repellent treatment for structural materials such as brickwork and stone. The silicone resins function by forming a water-repellent film on the surface of the capillary pores of the masonry to a depth of about 2–4 mm. ($\frac{1}{16}$–$\frac{1}{8}$ in.), depending upon the porosity of the masonry. In this way the pores are not blocked and the permeability of the masonry to vapours and gases ('breathing') is not seriously impaired. Based on American experience under conditions of average severity the treatment should have an effective life of 8 to 10 years. Resins used for this purpose are normally marketed as concentrated solutions in solvent which are diluted with suitable solvents to 2–5 per cent solids content for application.

Silicone Elastomers

Silicone elastomers or rubbers are based on linear polymers of very high molecular weight which are analogous to the silicone fluids. Mechanical strength is imparted by the addition of suitable inorganic fillers and the characteristic elastic properties are obtained as a result of intermolecular cross-linking in the presence of an oxidising curing agent such as benzoyl peroxide. Silicone rubbers are widely used in many applications where flexibility at extremes of temperature, beyond the limits of other synthetic or natural rubbers, is required. Silicone rubber is unique in retaining its flexibility at temperatures as low as −80° C.

Preparation

Silicone rubbers are based on gums of the following types: (*a*) dimethylpolysiloxanes, (*b*) gums in which some of the methyl groups have been replaced by phenyl groups; these give rubbers with outstanding flexibility at low temperatures, and (*c*) gums containing a small proportion, say 0·2 per cent molar of vinyl groups. The first step in the manufacture of dimethylpolysiloxane rubber gums involves treatment of the hydrolysis product of very pure dimethyldichlorosilane (in the form of cyclic methyl tetramer, i.e. octamethyl*cyclo*tetrasiloxane) with sodium hydroxide or sulphuric acid as equilibration catalysts in order to promote the formation of linear molecules of high molecular weight without cross-linking. A typical general-purpose rubber gum has an average molecular weight of 400,000 to 500,000, and a viscosity of 10 to 12 million centistokes. The silicone gums are true fluids in the Newtonian sense.

Fillers such as finely divided synthetic silicas (e.g. Santocel CS) or diatomaceous earths (Celite) are intimately mixed with the gum on mixing rolls similar to those used for processing natural rubber. Benzoyl peroxide is added at the same time. This produces a plastic mass (rubber compound) which can be moulded or extruded to the desired shape and cured to give an elastic product. The vulcanising action of benzoyl peroxide is believed to depend upon cross-linking of adjacent molecules involving oxidation and reaction between free radicals. There are two theories as to the nature of the linkages which are formed: (*a*) some authors believe that —Si—CH_2—CH_2—Si— bonds are formed between adjacent molecules: and (*b*) the formation of silcarbane linkages (—Si—CH_2—Si—) has also been suggested and is supported by the production of formaldehyde during the process. The bulk of the available evidence supports (*a*) as the predominant reaction.

Effect of Fillers and Additives on Properties

Although the constancy of properties of silicone rubbers in the range −80° to +250° C. is outstanding, at normal temperatures their physical properties such as tensile strength, maximum elongation and tear resistance are poor as compared with natural rubber. This problem is being actively investigated by several laboratories and rapid progress has been made in the last few years by studying the effect of new fillers and additives on the properties of the rubber. The newer fillers include vapour-phase silicas such as Aerosil, prepared from silicon tetrachloride. The use of this filler leads to a rubber with a very low water absorption and a tensile strength of 600–1,200 p.s.i. Silica fillers may be modified by treatment with chemical reagents to confer hydrophobic properties on the surface. Rubbers prepared from treated fillers have unusually high tensile strengths of 1,000 to 2,000 p.s.i.

The introduction of a small proportion of vinyl groups into rubber gums has led to increased ease of cure and to a marked improvement of compression set properties of the cured rubber. (Compression set is a measure of the set that the rubber retains after being maintained under compression.) With the advent of vinyl-containing rubbers, use of special compression set additives such as mercurous oxide, cadmium oxide and 2 : 5-*ditertiary* butylquinone has become obsolete.

The addition of polytetrafluoroethylene ('Teflon', 'Fluon') to silicone rubber yields a product with characteristic thermal stability but with improved tear strength, oil resistance and good low compression set properties. The product is known as 'Supertough' rubber.

Other Elastomeric Products

The properties and composition of silicone bonding pastes and 'bouncing putty' are closely related to the elastomers.

Bonding Pastes

The composition of the bonding pastes is similar to that of the rubbers except that the pastes contain a higher proportion of catalyst. The pastes are used for coating on to glass cloth and other textiles to produce high temperature electrical insulating materials. Similar paste-like mixtures are used for bonding silicone rubber, for bonding silicone rubber to metals, and as a bond between metals or glass. A typical bonding paste consists essentially of a rubber gum, calcium carbonate as filler and benzoyl peroxide.

'Bouncing Putty'

This plastic putty-like material, on account of its unusual combination of properties, is probably better known to the general public than other silicone products. Its characteristic properties, intermediate between silicone fluids and silicone rubbers, include: flow like a very viscous fluid on storage in a vessel; high elastic

rebound (about 80 per cent) when dropped on to a hard surface; brittleness on administration of a sudden blow; and plastic flow to form long threads on application of moderate tension. These properties depend in part upon the polyphasic nature of the material. In spite of its interesting properties no definite industrial uses have been established for this material in Europe.

'Bouncing putty' is prepared by heating a dimethylsilicone with boric oxide or other boron compounds and addition of suitable fillers.

Industrial Uses of Elastomers

Until recently the use of silicone rubber was restricted to military purposes. Its use in civilian aircraft and in numerous industrial applications is now well established. Silicone rubbers are used as gaskets in baking and drying ovens at temperatures as high as 300° C. and also in domestic refrigerators and refrigerated railway vans. Other applications calling for low temperature flexibility include aircraft door and bomb bay seals. The rubbers are also used in jet engines where unusually high and low temperatures are encountered. Silicone rubber switch boots are proving useful at the low temperatures and relatively high ozone concentrations encountered in aircraft at high altitudes. Silicone rubber-coated glass cloth ducting is used in anti-icing and heating systems in aircraft.

In the electrical field silicone rubber is employed as an insulator in power and control cables for naval use. The silicone is a major asset in this application in that, when the cable is damaged by fire, it leaves a residual silica ash, the insulating value of which is sufficient to maintain communication until the ship reaches harbour. The life of the cable under extreme temperature conditions is greatly superior to that of normal cables.

An interesting new use for silicone rubber is as tubing for blood transfusions. The rubber is more resistant to repeated sterilisations by autoclaving than natural rubber and it is transparent and practically colourless.

SUGGESTIONS FOR FURTHER READING

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LIFE AT LOW TEMPERATURES

SECTION D (Zoology), in joint session with Section I (Physiology and Biochemistry), devoted Thursday, August 28, 1958, at the Glasgow Meeting of the British Association to a symposium on life at low temperatures. The speakers were: Dr. A. S. Parkes, C.B.E., F.R.S., on 'Some biological effects of low temperatures' (Presidential Address, Section D, published in full in *The Advancement of Science*, No. 58, September 1958); Dr. K. Mellanby, C.B.E., 'The acclimatisation of insects to low temperatures'; Dr. J. W. Kanwisher, 'Freezing problems of marine life'; Dr. C. Polge, 'The freezing and storage of sperm'; Dr. D. W. H. Barnes, 'Treatment of lethally irradiated mice'; Dr. Audrey U. Smith, 'Resuscitation of frozen mammals'.

The following account of the papers which followed Dr. Parkes' Presidential Address has been prepared by Dr. K. Mellanby.

LIFE AT LOW TEMPERATURES

By Dr. Kenneth Mellanby, C.B.E.

(*Rothamsted Experimental Station*)

There have recently been several conferences dealing with the biological effects of low temperatures but the symposium arranged at the Glasgow meeting broke much new ground. It dealt with work on insects, marine invertebrates and mammals, and showed first that much progress has been made in all these fields in recent years, and, secondly, that there is still a need to co-ordinate the advances made in these different fields. It is possible that some apparently fundamental differences found between the reactions of, for instance, insect and mammalian tissues (or even between two species of insect, or two species of mammal) are produced by differences in experimental technique as much as by differences in the tissues themselves. At the same time, ecological studies reveal real differences in reaction to environmental factors which cannot be ignored, though the reasons advanced for these differences may sometimes have been incorrect.

Dr. A. S. Parkes' Presidential Address on 'Some biological effects of low temperatures', which so ably started the symposium and introduced the other papers, has already been printed in full (*The Advancement of Science*, No. 58, September 1958, pp. 46–53), and therefore is not dealt with here, though this article should be considered essentially as a continuation from it.

K. Mellanby, who spoke on 'The acclimatisation of insects to low temperatures', divided insects into three groups, according to their ability to withstand low temperatures. The first group is very resistant; these animals can survive after some (perhaps the greater part) of the water in their bodies has frozen, and cases of survival after immersion in liquid air have been reported. The second group may withstand temperatures considerably below freezing point, and may survive for periods of weeks or even months, but only so long as the body fluids are supercooled; if ice forms they die. The third group is the least resistant, and includes insects which are killed by exposure to temperatures a few degrees above freezing point.

Cold death is not the only important effect of low temperatures. Before death occurs, most insects are immobilised at the chill coma temperature, below which cold anaesthesia is seen. Even at a temperature at which activity is possible in an insect which is mechanically stimulated, it may seldom move spontaneously.

Unless the temperature of the environment is, for a reasonable part of the year, such that normal spontaneous activity occurs, survival of a species is obviously impossible. Changes in temperature have been shown to have complex effects on the nervous system (Kerkut and Taylor, 1958); thus a reduction in temperature may give rise to an increase in the intensity of the stimuli which cause activity, and at the same time it may affect the general metabolism so that activity, if it occurs, is sluggish. On the other hand a rise in temperature may increase the rate of metabolism, and the rate of possible movement when a stimulus is given, but little movement may actually take place because few spontaneous excitatory stimuli arise.

The first group of insects, able to survive being frozen at very low temperatures, has given many interesting results in recent years. It is perhaps noteworthy that some particularly cold-hardy species have been found to contain considerable amounts of glycerol in their bodies (Salt, 1958), an interesting parallel to the discovery by three of the other speakers at this meeting (Polge, Parkes and Smith, 1949) that glycerol protects mammalian cells at low temperatures. However, the correlation is not complete, for some hardy insects seem to contain little glycerol, and other species containing the substance are not resistant to cold. In most, if not all, cases in which insects survive freezing, the ice within the body is extra-cellular, and if ice forms inside the cell the insects die. This is similar to what has been found in other groups of animals, except when cooling has been so rapid that 'vitrification' takes place without the formation of detectable ice crystals.

Some acclimatisation occurs in insects which survive freezing. Thus goat moth larvae collected in summer are much less resistant than those collected in winter, and a hard winter makes the larvae more resistant than does a mild one (Smith, 1958). In some species the ability to survive these very low temperatures is obviously important, but the majority of insects avoid such conditions. Thus many insects burrow deeply into the soil during winter, and so experience much less extreme temperatures.

Most insects fall into the second category, i.e. they survive temperatures below 0° C. only if the water in their bodies is supercooled, and they die if ice forms. The degree of possible supercooling differs greatly from species to species. The haemolymph or 'blood' of insects, if removed from their bodies, has a freezing point less than 1° C. below zero, but it seldom freezes inside the body if the environmental temperature is in this region. Most insects which are not particularly hardy, such as fleshy caterpillars of Lepidoptera, can be cooled to —5° C. for some hours without damage, but a longer exposure or a slightly lower temperature causes freezing and death. Other insects have been cooled as low as —20° C. without freezing, and have been safely maintained at such temperatures. Eventually (after several months in extreme cases) supercooling may break down; the reason for this has not been discovered. In some of these species of insect there seems to be some degree of acclimatisation, so that specimens from warm conditions are less successfully supercooled than those from cool surroundings.

Sometimes supercooling breaks down and freezing takes place because of 'innoculation'. This is a very mysterious process. The cuticle of an insect, particularly at low temperatures, is almost, if not completely, waterproof. However, if a drop of water is placed on the outside of an insect, and it is cooled below freezing point, if the drop freezes then the water inside the insect freezes also. A similar insect with a dry skin will not freeze, and will survive.

One way in which, at the onset of winter, some insects become more frost-resistant is by reducing the proportion of water in their bodies. This has sometimes been thought to work by lowering the freezing point of the body fluids; however, such effects are very small, for the fluid from even the driest insect will still freeze above —1° C. The reduction of water would seem often to reduce the risk of

innoculation, either from the watery contents of the gut or due to wet excreta contaminating the cuticle. This is not the whole explanation, however. The ability to 'supercool' seems also to be related to the water content of the body.

The death of insects at temperatures above freezing point has not been investigated very thoroughly. The larva of the tropical yellow fever mosquito (*Aedes aegypti*) dies at +0·5° C., but the length of time it survives depends on its previous experience. Thus larvae from a culture at 30° C. all die in under 17 hours, whereas larvae from 17° C. survive this period (Mellanby, 1959). The cause of death is not understood. It cannot be asphyxiation, for the larvae from 17° C., which survive best, have the highest rate of metabolism. Several other insects, including the German cockroach, *Blattella germanica* (but not the common cockroach, *Blatta orientalis*) react in a similar manner (Calhoun, 1954).

Some work has been done on cold anaesthesia at temperatures above freezing point. After an exposure of only 24 hours many species became acclimatised to higher or lower temperatures, so that their chill coma temperatures are substantially altered. Thus cockroaches (*B. orientalis*) kept at 15° C. are able to move at 2° C., but those kept at 30° C. are immobile until the temperature rises to 7·5° C. (Mellanby, 1939). The same individual can be acclimatised to a high, then to a low temperature, and the process of alternation can be repeated many times. This rapid acclimatisation may effect not only the chill coma temperature but also the thermal death point (i.e. the lowest temperature where heat causes death), the cold death point and the position of the lowest temperature where normal activity takes place. Thus with larvae of *Aedes aegypti*, the 'Yellow Fever mosquito', the normal alarm reaction (larvae usually remain near the water surface, but when 'alarmed' by vibration or a sudden reduction in light they swim to the bottom) is not given until several degrees above the chill coma temperature (Mellanby, 1958).

	Acclimatisation temperature °C.		
	10	*17*	*34*
Chill coma temperature, °C.	3·4	5·7	10·8
Alarm reaction starts at °C.	9·0	11·0	14·3

In most cases it seems that there is only negligible acclimatisation within one hour, some in 3 hours, and that the process is complete within about 18 hours. This acclimatisation, which is so rapidly achieved and lost under conditions permitting activity, may sometimes be much more long lasting. Thus mealworm larvae (*Tenebrio molitor*) survive for several weeks at 0° C. even when transferred from warm conditions, but the time they take to recover activity when returned to 'room temperature' depends on their exposure before chilling.

The mechanism of this rapid acclimatisation is still a mystery. It would seem likely that the same process governs the changes in heat resistance, cold resistance and ability to move. Many theories have been advanced, often depending on changes in protoplasmic viscosity. This seems unlikely to be the whole explanation, for in insects which can have vastly different water contents acclimatisation seems equally rapid in partly-dehydrated and in undehydrate individuals.

Much of the work on insects dealt with temperatures above freezing point, while the other papers in the symposium all dealt with sub-zero conditions. In insects it seems likely that the same sort of mechanisms were at work at temperatures above and below freezing, and this may suggest that freezing is not, as a phenomenon, of such fundamental importance as has sometimes been imagined.

Effects of sub-zero temperatures on marine animals were described by J. W. Kanwisher. On the shore of Woods Hole, Massachusetts, in North America, during the winter temperatures as low as −30° C. are reached, and −15° C. is a common occurrence. Intertidal animals are exposed to these conditions, and they may freeze

and thaw twice a day. Animals of the same or similar species occurring in the Arctic may remain frozen for as long as six months. It has been shown that these shore-dwelling animals have body temperatures which are almost exactly the same as those of the air surrounding them (Kanwisher, 1955). Survival is not due to supercooling, for more than half of the water in the bodies of these animals is turned into crystalline ice. What appears so remarkable—though it is evidently a common occurrence, only remarkable in being so long unobserved and undiscovered—is that no injury is produced when this great bulk of ice is produced.

The histological changes which accompany freezing are surprising. Kanwisher used the freeze-drying technique, in which the tissue is cooled very quickly with liquid nitrogen, so that ice crystals do not have time to grow and cellular organisation is little disturbed. The water is removed in a vacuum at −45° C. The results obtained with normal, unfrozen, tissue (Fig. 1, A, C, E) show how satisfactory the method can be.

Animals were collected on the shore at Woods Hole at low tide in January, and taken to a room at −10° C. without thawing. They were cut into slices 1 mm. thick with a cold knife, and then prepared for histological examination. Fig. 1, B, D, F show the results. In all cases extreme distortion, due to extra-cellular ice crystals, is apparent. If, however, the tissue was thawed before being prepared for sectioning, it became quite normal in appearance. This happened even if a 1 mm. frozen slice prepared as already described was divided into two, part thawed for one minute and the other sectioned without thawing. The former appeared quite normal, the latter grossly distorted. If any zoologist unaware of this work were shown the distorted, frozen specimens, he would certainly say they were from dead, if not decomposed, animals. It is difficult to conceive how they recover and survive such drastic treatment twice a day for several months of the year.

The rate of metabolism of these littorine animals was measured both above and below freezing point using the method described by Scholander (1947); results typical of many are given for one species (Fig. 2). It will be seen that above 0° C. the rate of respiration falls in a manner similar to that described in most poikilothermic animals and the Q_{10} for the rate of decrease is between 2 and 3. Below zero, however, respiration becomes much less, and there is an apparent Q_{10} of about 50. This decrease is apparently due to several causes, one of which is the high salinity in which the cells are immersed when the bulk of the water in the animal's body is frozen. A remarkable thing about these animals is that they survive not only the cold and the spectacular distortion of their tissues, but also being 'pickled' in extremely strong brine.

Supercooling does not seem important in shore living animals, but it is important in teleost fish in Arctic waters. These may swim actively below the ice in water at a temperature of −1·7° C. Their blood may, under these circumstances, become more concentrated than in fish in warmer waters, but they are still supercooled by about half a degree. If brought to the surface ice crystals may form on the skin and cause them to freeze, in the same way as insects freeze when ice forms on cuticle of supercooled individuals, but in deep waters this does not happen. The interesting fact is that these supercooled fish are quite active; most animals previously described in this state were in cold anaesthesia.

C. Polge was one of the original workers who showed that if glycerol is added to sperm, it may survive freezing, storing at very low temperatures, and thawing (Polge, Parkes and Smith, 1949). He reviewed recent work on freezing and storage of sperm in which he has played the leading part.

Sperm from different species differs greatly in its resistance to low temperatures. Human sperm is more resistant than any that has yet been studied. It may, even without treatment with glycerol, survive rapid freezing by immersion in liquid nitrogen at −196° C. Human pregnancies have been reported in the U.S.A.

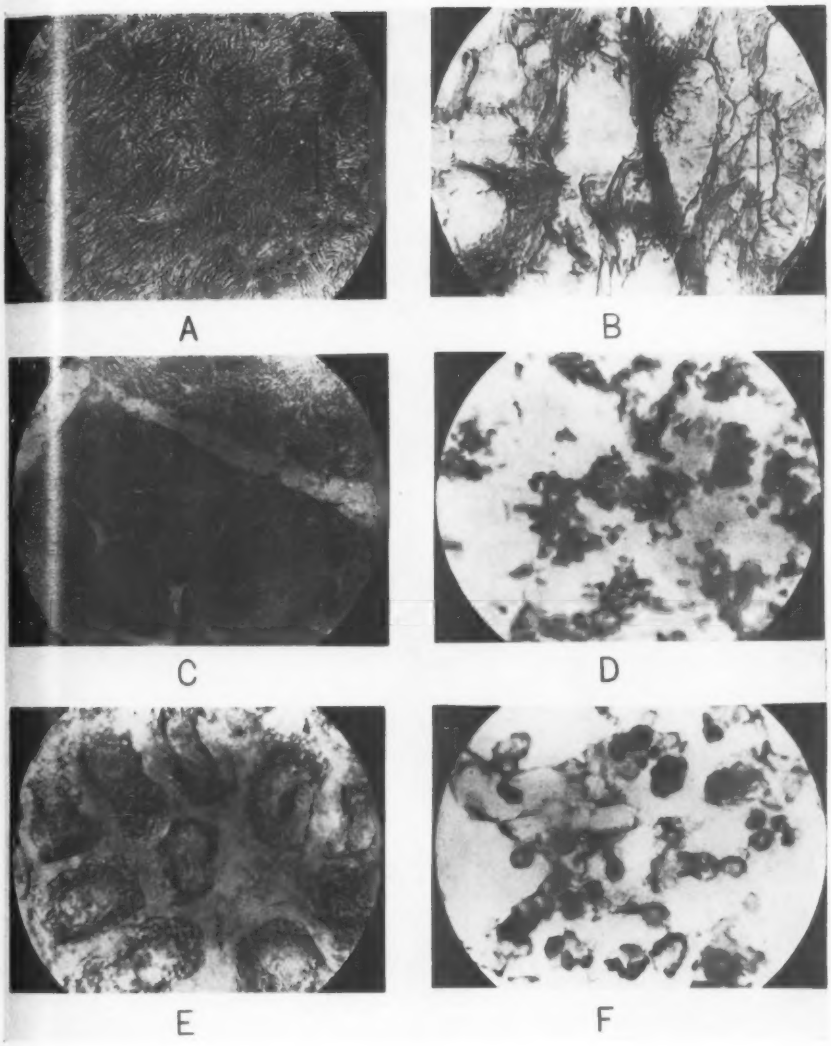

Fig. 1.—Frozen intertidal animals.

A and B. Foot muscle of shore snail, *Littorina littorea*. A, unfrozen, B, frozen.
C and D. Adductor muscle of the oyster *Ostrea virginicus*. C, unfrozen, D, frozen.
E and F. Ovary of the mussel *Mytilus edulis*. E, unfrozen, F, frozen.

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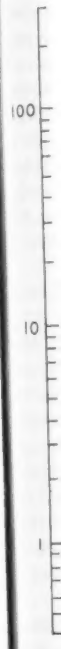
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following the use of glycerol-treated frozen semen but work on these lines has not been reported in Britain.

Bull semen has given the most satisfactory results of any domestic animals, so that storing in the frozen state has become a normal practice. An addition of 10 per cent of glycerol has been found to give optimum results in this species, and the rate of cooling is carefully controlled. This must be fairly slow until about $-30°$ C., after which it can be more rapid. Sperm stored at $-79°$ C. has retained its potency unimpaired for 5 years (the duration of the experiment to date) and calves have been conceived several years after their father's death. A very valuable technique which should lead to important livestock improvement has been developed.

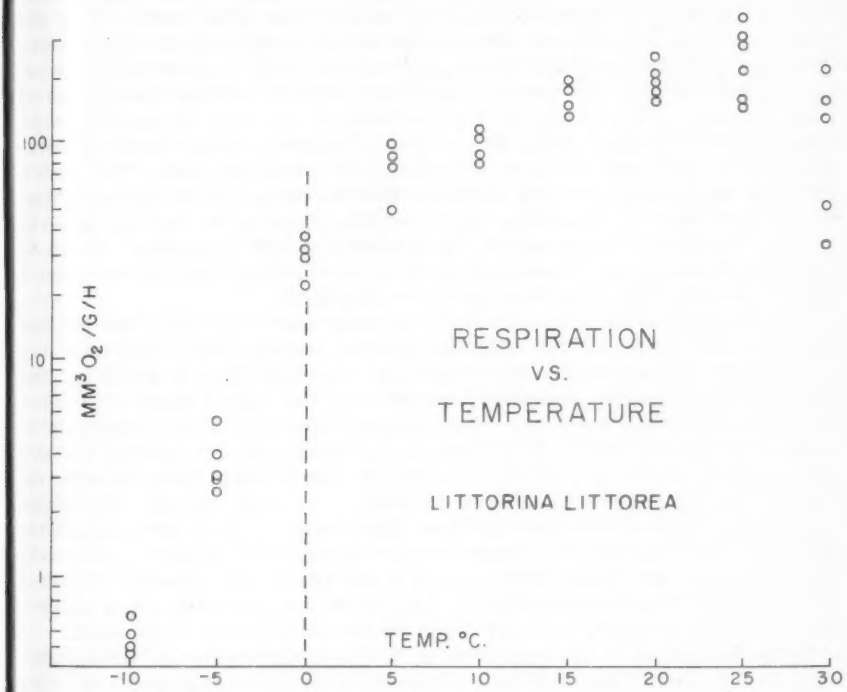

Fig. 2.—Rate of respiration of shore snail, *Littorina littorea*, at temperatures from $-10°$C. to $+30°$C.

Work on other animals is still in the experimental stage. Ram, stallion, boar, rabbit and fowl sperm have been found to differ greatly in their resistance. These differences appeared at first to be fundamental ones, but further work has shown that they are mainly ones of degree. It seems, for instance, that the exact concentration of glycerol added before freezing is important, as is the period of equilibration, that is to say the period which elapses between the addition of the glycerol and the onset of freezing. The optimum rate of cooling must also be determined separately for each species.

This work is complicated by the fact that two criteria for survival of sperm have been used; these are motility, and the ability to fertilise and cause pregnancy. Sperm which is immotile after freezing is obviously useless, but sperm which appears normally active may not be capable of fertilising the egg. Thus ram semen, in some experiments, appeared quite normal when examined microscopically, yet

it caused few pregnancies. That it caused some is an indication that it should not be long before it can be stored as easily as semen from the bull.

Glycerol seems to act by reducing the effect of the concentration of salts which occurs when the water is removed as ice during slow freezing. Rapid freezing avoids the difficulties due to this concentration of salts, but the additional complication of temperature-shock is introduced. The differences in reaction of the sperm from the different animals are now being analysed in relation to these factors, and a rational explanation of these very complex results is now emerging. These intensive studies on sperm may also help to explain results which have been obtained with other tissues and from other animals.

A great deal of work is in progress on ways of reducing the damage done to animals (and man) by radiation. Various chemicals given *before* radiation may give some protection. Hypothermia *during* radiation may render animals less sensitive. Thus though reduction of the body temperature to 20–29° C. gives no protection, mice cooled to 0·5° C. can survive much greater doses of radiation than can normal mice (Hornsey, 1957). D. W. H. Barnes described still more remarkable experiments, where treatment given *after* a dose of radiation which would otherwise have proved fatal was shown to save the life of laboratory mice. This work is clearly of the greatest practical and theoretical importance; it is dealt with more briefly here than its importance might warrant, because it does not primarily concern 'life at low temperatures'. Its inclusion in this symposium was amply warranted, however, as a demonstration of one way in which work on the effects of low temperatures may help investigators in other fields.

It was first found that if mice were given a lethal dose of radiation (950 r) all died within a week. If immediately after the radiation mushed spleen from baby mice was injected intravenously, most of the mice survived. Later it was found that tissues from guinea-pigs and rats would also save the mice. Careful experiments showed that this only happened if the injected tissues were viable; they could be stored with glycerol at −80° C. undamaged, and then proved completely effective, but storage at +4° C. or −15° C., or in one per cent formalin, killed the cells, and did not protect the irradiated mice in which they were injected. Histological examinations have shown that cells from rats actually survived and multiplied in the mice. This is because the normal immune response is temporarily abolished by the radiation, a fact proved further when it was shown that a successful graft of rat skin could be made to the mice. Techniques for storing tissues at low temperatures are likely to play a vital part in the further development of this work.

In the final paper of the symposium, A. U. Smith dealt with the 'Resuscitation of frozen mammals'. An interesting historical survey included accounts of several men who had been found during the last two or three hundred years, apparently 'frozen to death', but who had eventually recovered. No one has satisfactorily explained what really happened, for many workers from Claude Bernard onwards have shown that though homothermous mammals can have their body temperatures reduced considerably from the normal 37° or 38° C., if the body temperature falls to somewhere in the region between 15° and 25° C. they do not recover on return to normal conditions. The only exceptions are mammals which hibernate. These become poikilothermic during their dormant period, and are undamaged when their body temperature falls to only five degrees above freezing point.

Hypothermia in man is used in surgery. When the internal body temperature falls to between 28° and 30° C., anaesthesia is produced, and surgical operations can be performed. The oxygen requirements of the brain and other vital organs are greatly reduced, so that the circulation of the blood can be stopped for up to eight minutes without any permanent damage to the patient. We know that if the temperature could be reduced to below 10° C. the rate of metabolism would fall much further, and extra time would be provided for the surgeon. Unfortunately this

extra cooling of man is not, at present, practicable. We know that if a man is cooled below 25° C., using the methods of warming and resuscitation now available, survival is unlikely.

The present writer was strongly reminded of his investigations of the notorious experiments carried out in German concentration camps by a Dr. Rascher (Mellanby, 1947). The unfortunate victims of these atrocities were forcibly held down in baths of ice and water until their temperature fell. The work was not only unethical, but was open to criticism on scientific grounds, but the records show that prisoners cooled to 25° C. and rapidly warmed by immersion in a bath of warm water (or warmed by less conventional means including 'body warmth' applied by naked gypsy women who were also prisoners of the Nazis) usually survived, but those cooled below 24° C. always died. Rapid rewarming, instead of slowly applying heat as had previously been advocated, was shown to give much better chances of survival. This finding is of interest when considering the experiments described below, for the method of reviving chilled or frozen animals is seen to be of primary importance.

Until about ten years ago, there seemed no possibility to the scientist that mammals could be revived after cooling below about 15° C., though cartoonists and writers of science-fiction have described freezing and thawing of their characters. However R. K. Andjus was not deterred by the 'impossible', and found that rats cooled so that their deep body temperature fell to between 0° and 2° C., when breathing and heartbeat had stopped for an hour, could still be reanimated. The important thing was the method of reanimation; in these early experiments this was done by applying a hot spatula to the chest, blowing air into the lungs, placing in a hot bath, etc. Only a few of the rats recovered completely under this treatment, but an entirely new principle was established when *any* were found to survive.

The next stage in this work was to improve the methods of reviving animals cooled to just above freezing point (Andjus and Smith, 1954, 1955). Successful results were obtained using radiant heat apparatus of various designs, and microwaves generated by a magnetron and focused on the heart, but eventually a simple method of warming the body with ordinary electric light bulbs combined with artificial respiration proved most effective. Many workers now regularly cool small mammals to temperatures just above freezing point and revive them after this exposure. The ease with which this is done is a measure of the success of the work of Andjus, Smith, Parkes and others, for the 'impossible' has almost become the commonplace. Results relating to other fields are already appearing. It has already been stated that mice cooled to just above freezing point withstand radiation that would be fatal at normal body temperatures (Hornsey, 1957). Rats cooled to low temperatures for two hours do not 'forget' how to solve problems like finding their way through a maze, though the activity of the brain has been arrested (as judged by electroencephalograms). This contradicts the theory that memory depends on continuous activity in the brain (Russell, 1956). Workers in the fields of experimental physiology and psychology have been given a most valuable new approach. It is also surely only a matter of time before this work is applied to man, so that surgical anaesthesia can be prolonged at much lower temperatures than are at present used.

The experiments described so far deal with body temperatures above freezing point. Dr. Smith and her colleagues next went on to try to find out whether mammals would survive reduction of the body temperature to lower levels below the freezing point of blood and tissue fluids, and further whether it was possible to extend to the whole animal work (described above, p. 413, for sperm and other tissues) on the preservation of living cells in the frozen state at very low temperatures.

In the first instance the golden hamster was used. This animal hibernates, and its temperature can readily be reduced to about 2° C., when the heart continues to

beat very slowly and breathing is not entirely eliminated. Hamsters can rouse themselves from these low temperatures, a thing rats and mice cannot do. In nature hamsters never freeze and thaw; these processes are just as unnatural and dangerous to hamsters as to mice or men. Hamsters were first enclosed in a glass jar packed in ice. They rebreathed their own expired air, and the falling oxygen tension and rising CO_2 content of the cold atmosphere anaesthetised them. Hamsters so treated were packed into crushed ice and cooled to 2·5° C. Finally they were transferred to a bath of propylene glycol at −5° C.; this could subsequently be cooled even further. In under 10 minutes the internal temperature fell to zero; after this three different types of temperature curve were obtained.

In about 25 per cent of the animals the deep body temperature continued to fall, to as low as −6·0° C. These animals remained soft and unfrozen and no ice was formed in any of the body fluids or tissues, as they were in the supercooled state. When supercooled hamsters were rewarmed either under a bench lamp or with diathermy the temperature rose steadily and the heart resumed beating and, provided that artificial respiration was given, they recovered fully.

In some of the supercooled animals the body temperature rose suddenly to a level at about −0·6° C. although they were still in the bath at −5° to −8° C. Simultaneously, the body began to stiffen and it was clear that freezing had taken place. The internal temperature had risen because of the evolution of the latent heat of crystallisation, it became stabilised at a level corresponding to the freezing point of plasma (−0·56° C.). Hamsters which had crystallised spontaneously after supercooling to temperatures as low as −3° C. usually recovered fully when rewarmed and given artificial respiration. Those which had crystallised after supercooling to temperatures between −3·5° and −6·0° C. seldom recovered fully although the heart usually resumed beating temporarily. It seems that the sudden formation of a large quantity of ice throughout the body, which occurs when freezing follows 3 degrees of supercooling, is lethal even if the animal is rewarmed immediately after the temperature rises.

In about 75 per cent of animals the cooling curve was entirely different. The deep body temperature of the hamsters lying in the −5° C. bath fell below 0° C., and then stabilised at about −0·6° C., only falling very slightly during the next hour. Meanwhile the ears, paws and whole body wall became stiff and hard and it was quite evident that the animals were freezing progressively. Ice crystals could be seen in the skin, and ice was found in the subcutaneous tissues, the abdominal and thoracic organs, and in the brain itself in animals which were sacrificed during this period. Even at the end of an hour of progressive freezing at −5° C. there was still some liquid blood in the chambers of the heart and in the centre of the liver and kidneys. Determinations of the ice content showed that 90 per cent of the water in the subcutaneous tissue, 62 per cent in the brain and 50 per cent of the water in the entire body had been turned into ice. Nevertheless, hamsters which had been frozen for periods up to one hour at −5° C. and in which up to 50 per cent of the body water was frozen, recovered fully when the whole body was rewarmed with diathermy and when artificial respiration was given. In spite of the large quantities of ice present in the skin, they were not usually frost-bitten. The only animals in which frost-bite regularly occurred were those in which the ears or the paws had been bent while they were frozen stiff. By contrast, animals which had been frozen at −10° C. for comparatively short periods all showed frost-bite when rewarmed and none recovered fully.

So far it has proved impossible to revive successfully larger animals after they have been frozen. Many difficulties were encountered in the attempt. It was difficult to cool these animals sufficiently unless the bath was so cold as to induce superficial frost-bite; this was overcome by shaving the fur, and vigorous stirring of the bath. Some rabbits and *Galagos* made an initial recovery, but died in a few

hours. Some internal organs were clearly affected; in some it was thought that hydrochloric acid in the stomach was corroding the blood vessels, so bicarbonate was administered with beneficial results, but these were not sufficient as other organs were similarly damaged.

At this stage it was decided to experiment with individual organs, before doing more work on the intact animal. Guinea pig uteri have recovered after having been frozen at −79° C. in a medium containing glycerol and free from calcium. Hamster hearts survived the same temperature, though they were not normal at the end of the experiment. It seems possible that eventually if a proper perfusion liquid can be found, it may be practicable to keep alive whole animals at very low temperatures in the frozen state.

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LIVING MACHINERY AND THE ELECTRON MICROSCOPE[1]

by

DR. C. F. A. PANTIN, F.R.S.

THE grand problem of Biology is, what makes living things alive? What makes the difference between them and inanimate physical objects? Though the problem is still unsolved, we know a very great deal more about it than we did when modern science began 300 years ago. During that time advance of knowledge has gone hand in hand with the discovery of new scientific instruments; instruments to help accurate measurement, like telescopes and clocks; instruments to help us do what we cannot do with our hands alone, like electric motors and nuclear reactors; and very particularly, instruments which enable us to see new natural phenomena we cannot see with our unaided eyes. For Natural Science cannot deal with natural phenomena which we do not know exist. Our 'sensory spectrum' is so limited. So much that happens is too fast or too slow for us to realise by our unaided senses that anything is happening. So much is too large or too small for us to comprehend. For that reason the invention of the light microscope in the seventeenth century opened a new and unsuspected world to the early scientists. And the same thing has happened today through the invention of the electron microscope, an instrument which promises to carry our power of seeing the minute to its ultimate chemical limits. Thereby it is transforming our knowledge of the organisation of the living substance. Let us see how that has come about.

Living organisms are material systems made of matter and energy, and they obey the same laws of physics and chemistry as those of the inorganic world. Whatever else may be said about them—and there are some very important things which may be said, particularly about consciousness and behaviour, with which I shall not deal—their bodies resemble machines; machines for reproduction, for feeding and so on. This fact brings biology closer to engineering than it does to much of present-day physics. It is important to ask what the wing of a bird is 'for', and it is important to ask what a sparking plug is 'for', but the physical scientist cannot ask what a carbon atom or an electron is 'for' in the same way.

Like machines, living organisms require material for their construction and fuel to supply energy to run them. That great Glasgow physicist Lord Kelvin once said that the test for our understanding of a natural phenomenon is, 'Can we make a mechanical model of it?' If we can—even in theory—we can claim to understand it; if not we cannot make that claim. To understand a petrol engine we only have to study the gross structure of its parts—its pistons, valves, and so on. We can certainly make a model of it. We do not have to worry about the ultimate molecular structure of the cylinder or of the petrol which it uses. In living things the machinery is on a much smaller scale. The structural units, whether they are those which cause contraction in muscle, conduction of excitation in nerves or any other process, are the individual cells which compose the tissues of the body. It is these cells which somehow provide the machinery upon which life itself depends.

Fig. 3c shows a muscle cell from a sea-anemone. We can see in it various structures such as the basal muscle fibre that contracts, the darkly stained nucleus and the mass of protoplasm around it. But the nature of this machinery of cells is not

[1] Discourse delivered in St. Andrews Hall on September 1, 1958, during the Glasgow Meeting of the British Association.

self-evident to our unaided senses, like that of a petrol engine. How can we proceed in our quest for a mechanical model of it?

When we observe what animals do it is clear that the chemical processes of their cells are elaborately directed to special needs such as behaviour, reproduction and so on. The ultimate chemical processes on which these needs depend are anything but simple. In the March, 1958, number of *The Advancement of Science* there is an elaborate diagram which shows us what the biochemists know about the fate of sugar in the living body (Fig. 1). What happens is very complicated. But even without understanding the chemical nature of the substances which intervene between sugar and its various end-products in the body, it is at once clear that these chains of biochemical events in the cell are very like the chains of events in a well-ordered factory; where raw materials are taken in and passed down a variety of assembly lines to give rise to a variety of finished products.

Where is this ultimate machinery which fashions these products in the living cell? If we grind up living cells we find a great variety of different substances and that all sorts of reactions can go on in the ground-up mass, but the ordered direction of the chemical reactions that we see in the living cell is no longer there. Like a factory, cells must possess some kind of organised machinery.

Microscopists have for some time realised that the cell contains a series of minute organs. There is the nucleus itself which, so to speak, provides the jigs and patterns upon which various living materials are built up, but there are also contractile fibres and other structures known as 'mitochondria', 'microsomes' and so on. It can be shown that these are, in fact, individual biochemical 'sub-machines' for dealing with certain special chemical reactions. Originally these structures were only seen in cells that were killed and preserved. It was not certain whether they really existed in life or whether they were the artificial result of precipitation. But even thirty years ago Strangeways and Canti actually showed these structures in living cells artificially cultivated from embryos from hen's eggs (Fig. 2A).

Unfortunately these cell structures are almost all just on the limits of what we can see with ordinary optical instruments such as the light microscope. The difficulty is this. We see things with the ordinary microscope by means of light, but light itself consists of waves, and these are of a definite size. For visible light the waves are about 1/2,000th of a millimetre long—say 1/50,000th of an inch. The image that one sees with the naked eye or through the lenses of the light microscope is made up of these waves. It is, so to speak, 'painted' with a brush that is about 1/2,000th of a millimetre broad. Consequently there is a limit to the fineness of the detail which one can appreciate. However much we magnify, physically it is impossible to see the detail of objects if this is smaller than about 1/4,000th of a millimetre or, say, 1/100,000th of an inch in size; and that is just about the size of the sub-machines in the living cell.

This is where the electron microscope has proved of such immense value. On theoretical grounds physicists showed the surprising fact that the electron, which carries the electric current can behave as though it were a train of waves. From that it followed that if we project streams of electrons on to an object we might use them in much the same way as we can use rays of light. But the size of the electron waves is far smaller than those of visible light. The electron microscope at the Cavendish Laboratory in Cambridge works at 80 kilovolts and the effective length of the electron waves is of the order of 1/1,000 millionth part of an inch. That is, in fact, less than 1/100th the size, not merely of a molecule, but of the atoms of which chemical substances are composed. If we could 'see' things with electrons, instead of light, the 'paintbrush' would be, so to speak, about 100,000 times finer than it is with the light microscope.

But in spite of the great difference in size between electron waves and light waves, the electron microscope is built upon what is really the same principle as the

light microscope. In both we need lenses to focus the image of the things we want to look at. But whereas with the optical instrument we use glass lenses to focus the light thrown on the specimen, in the electron microscope we use powerful electric magnets to focus a beam of electrons thrown upon it. We can do this because the direction of a stream of electrons is easily deflected by a magnetic field.

The electron image can be made visible by throwing it on a fluorescent screen—just as with X-rays—or it can be photographed. With an instrument of this sort magnification can be carried far beyond that with the light microscope. During the last twenty years there has been a steady and rapid improvement in these instruments, and though we are still far from the limit of magnification which is theoretically possible, the instruments have been so far improved that we can already see with the electron microscope things which are no larger than rather large molecules —that is, structures of about 1/10 millionth of a millimetre, or 1/250 millionth of an inch.

There are, of course, difficulties in dealing with the instrument because we can only investigate living tissues by it in very small pieces, and after they have been killed and subjected to rather drastic treatment. As in the early days of the light microscope it is not always too clear whether what we can see corresponds to what was originally present in the living cell or whether it is the product of what we have done to its dead remains. Usually the tissue to be examined is embedded in a plastic resin and then cut into slices for examination. This is done on much the same principle as that by which a grocer slices ham—except that whereas the rashers are about 1/10th inch thick, the thickness of the tissue slices is about 1/20th of the wavelength of light. For such exceedingly thin slices a very sharp knife is needed, and this is supplied by a flake of glass—the sharpest knife ever known is still that discovered by Stone Age man when he first chipped flint and obsidian.

But the difficulties of the instrument are being overcome. To see what it can do let us apply it to the tissues of a very simple kind of animal—a sea-anemone such as that shown in Fig. 2B. So much biological work is done on structurally complicated animals like ourselves that there is often great advantage in turning to simple ones instead. The most important activity of any living animal is the power of movement. As in the higher animals the movements are due to muscle. The body of a sea-anemone is essentially a muscular bag full of sea-water. The sheets of its tissue can be seen to be muscular (Fig. 2C). What is the structure of the muscle? Slices of its muscle can be investigated with increasing magnification of the light microscope (Fig. 2D). At high magnification we can easily see in cross-section the muscle fibres which cause the movement of the animal. Fig. 2E shows these muscle fibres in section under the highest optical magnification. But at this magnification the size of the light waves by which the image is seen is appreciable and it is for this reason that the picture lacks precision. Let us now pass to a low-power electron microscope picture of a similar structure (Fig. 2F). The greatly increased power to resolve detail is at once clear. The magnification can be further greatly increased till we reach the present limit of the instrument, as in Fig. 3B. The presence of much of this fine structure in the living cell can be confirmed indirectly by physiological experiment; so that although what we see is extremely small we know that it corresponds to something which does the work in the living animal. How very small it is can be realised by remembering that if the whole sea-anemone were magnified by the same amount as the picture in Fig. 3B it would stand about four miles high. A man on the same scale would stretch from London to Birmingham.

The larger chemical molecules, like those of protein, may be 1/20,000 millimetre long; a distance represented by several millimetres in Fig. 3B. So at this great degree of magnification we might expect to see evidence of the individual molecules of which the tissues are composed. That expectation is justified. Like the muscles of our own intestines, the muscle fibres of sea-anemones are attached to fibrous

'connective tissue' somewhat resembling cotton wool—except that the fibres are far smaller. Fig. 4B shows the fibres—the same kind of fibres seen in cross-section in Fig. 3B. It will be seen that under the electron microscope, after an appropriate staining treatment, the fibres show a regular banded appearance. Each fibre in fact consists of chains of molecules, and the end of each molecular link stains differently from the middle part, so that the banding gives direct evidence of the molecules of which the fibre is composed.

To appreciate the significance of this organisation it is useful to compare the structure of a living animal with that of the engineering models, such as a crane, that a boy makes with one of those constructional toys. Like the animal the boy's crane is a functional machine doing a certain job. It is, in fact, constructed of standard parts which are supplied in the sets that it is built from. In the crane there are two elements in its structure—the functional element which makes it a crane and also the element which is due to the fact that it is built up of standard parts whose presence quite clearly affects the picture we see. Exactly the same thing is really true of living organisms. When we look at the ultimate parts of the cell we see in fact evidence of the standard parts, the molecules out of which the machine is built. There is only this difference, that compared with the size of the parts the size of the animal itself is so vast that the individual bricks out of which it is built can no longer be seen. A sea-anemone four miles high built out of Meccano would no longer show the individual nuts and bolts; compare Figs. 4A and B with C and D.

The orderliness imposed on living structure by the standard molecules of which it is composed does not end simply with the molecules. In machinery, the ultimate units of wire, wheels and so on can be built up into standard units of a higher order such as electric motors; and electric motors on the same plan are repeatedly to be seen in different kinds of machines. The same principle is seen in living structure. Not only are there ultimate molecular units, but these are built up into machines of standard pattern. This is particularly striking in the cellular machinery responsible for movement. Thus in the muscle fibres of many different kinds of animals the molecules are organised on a large enough scale to give the same striated appearance visible to the eye with the light microscope. It is also clear in another sort of cell-machinery which causes movement. Many cells are covered with fine whip-like processes, known as cilia or flagella. These continually lash along any fluid or movable material in contact with the cell.

We find these cilia and flagella on the surface of our respiratory tracts, where they whip the mucus which would otherwise accumulate there out of our lungs. This sort of action is common in animals of almost every kind. Thus the gills of oysters and mussels are continually cleared of mucus together with detritus, which is carried in from the sea-water in which they live. This clearance is done by cilia, and micro-cinematographic studies can show these cilia in operation. These minute whips are about 1/25,000th inch thick. The cell from a sea-anemone, shown in Fig. 3B, can be seen to have a cilium arising from its outer surface.

Biochemists have shown that the chemical processes by which muscles, cilia and even naked protoplasm like that of Amoeba work are essentially the same. The difference between them is in the organisation of the molecules into larger contractile units in each case. In muscles there are long strands of protein fibres that we have already seen, and which actually cause a contraction of the muscle. In a cilium there is a highly characteristic arrangement of contractile fibres. Fig. 3D shows a cilium on a cell which has been sliced through vertically—like a piece of firewood. Within each minute cilium there is a system of eleven flexible threads or rods. In cross-section they have an arrangement a little reminiscent of the stones in Stonehenge. There are two in the middle and a ring of nine surrounds them. These appear to be the actual contractile structures. What is more, throughout the

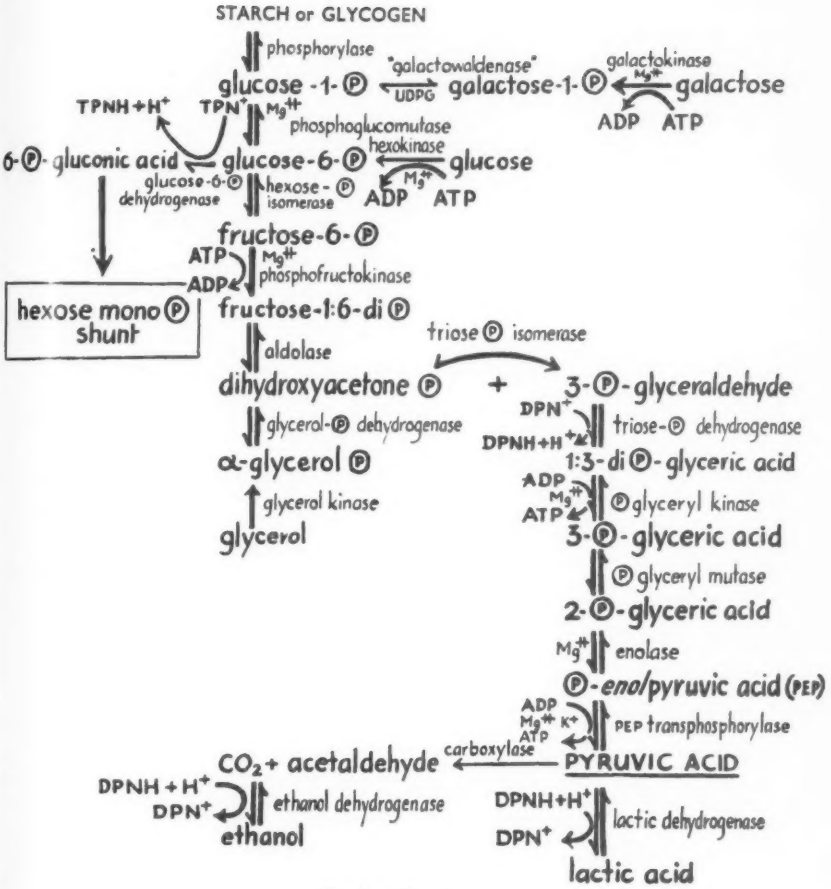

Fig. 1.—Glycolysis.

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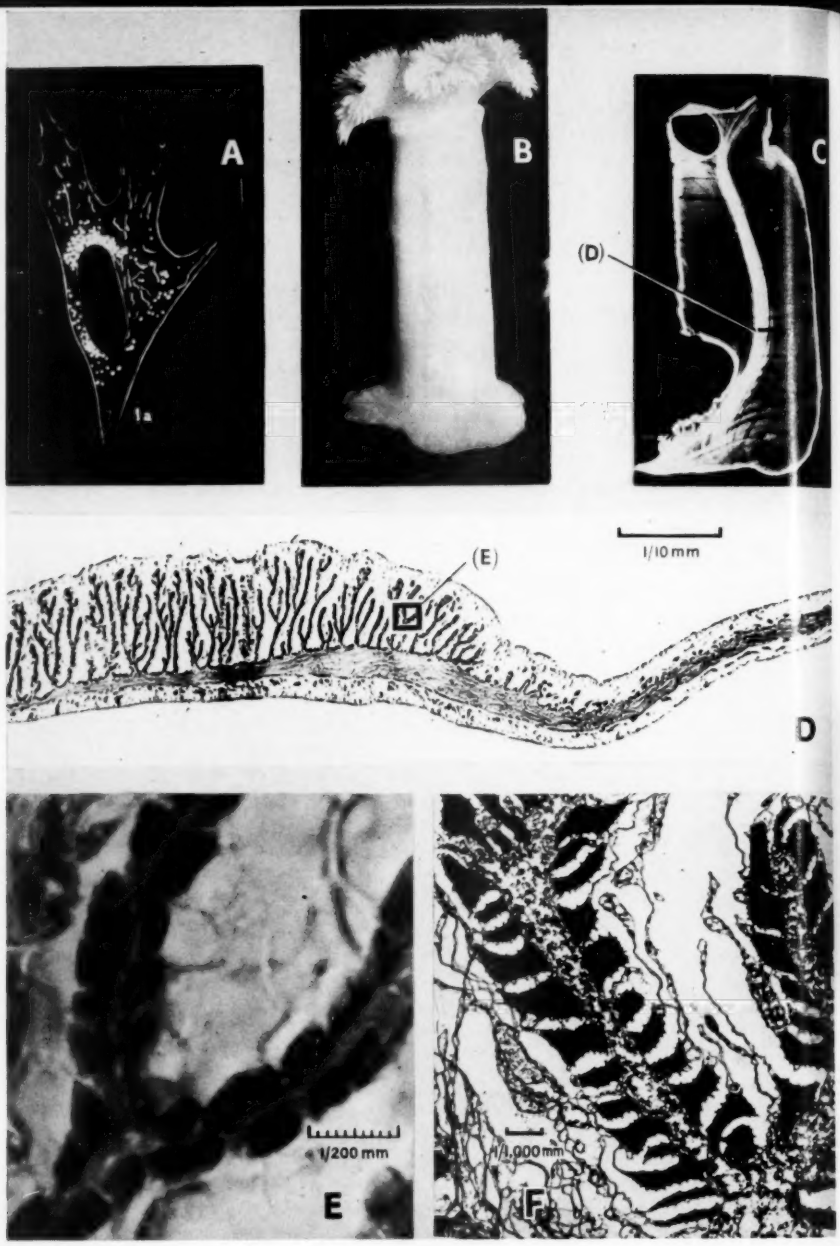

Fig. 2.—A. Living embryonic cell of a chick, in tissue-culture, by dark-ground illumination. Note thread-like mitochondria, fat droplets and nucleus.

B. Expanded living sea-anemone, *Metridium senile*, about 3 in. tall.

C. One of the muscle sheets (mesenteries) within *Metridium* attaching the upper surface and tentacles to the body wall (right) and to the base (attached to the rock in B). Note the long white retractor muscle which pulls in the tentacles. The transverse line (D) shows the position of the section shown in 2D. Preparation by Dr. E. J. Batham.

D. Thin cross-section of a muscle sheet as in C, from a smaller anemone (*Aiptasia*) related to *Metridium*. The folded layer of muscle fibres runs along the surface of (grey) fibrous connective tissue. The individual muscle fibres can just be seen as black dots. The inset (E) is enlarged in 2E.

E. Cross-section (inset (E)) of retractor of *Aiptasia* under maximal magnification by light microscope (1·5 mm. oil immersion objective). Muscle fibres can be seen attached to both sides of the thin branching sheet of connective tissue. The divisions of the scale are at 1/2,000 mm. the wavelength of green light.

F. Very thin cross-section of retractor muscle of *Metridium* under low electron-microscope magnification. Note very much greater resolution of detail than in E: muscle fibres with protoplasmic extensions and fibrils of the connective tissue are clearly seen.

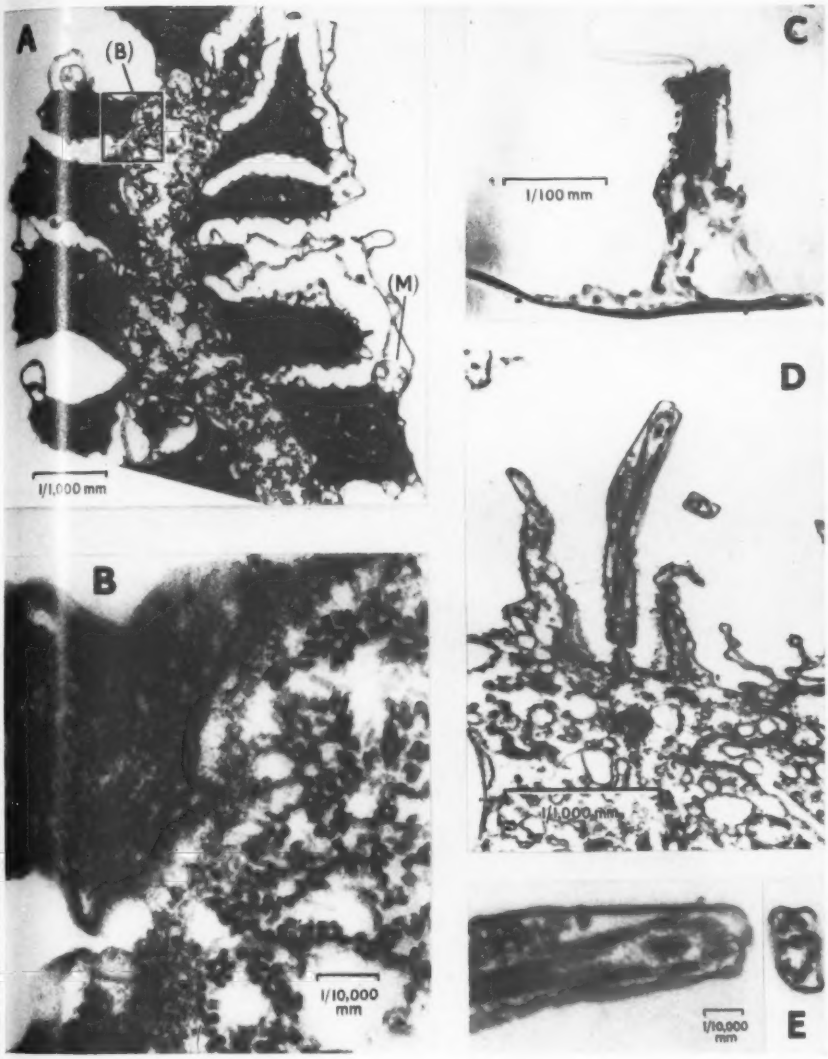

Fig. 3.—A. Electron micrograph, intermediate magnification, of a fold of the retractor muscle. (M)=mitochondrion.

B. Electron micrograph. Inset marked (B) enlarged maximally. Note detail of fibrous connective tissue on right and contractile filaments of muscle fibre in parts of muscle cell on the left, and also the boundary membrane of the cell.

C. An isolated muscle cell of a sea-anemone *Metridium* seen under the light microscope. The dark muscle fibre runs at its base, the protoplasm contains a darkly stained nucleus, and above can just be seen a whip like cilium arising from it (the double appearance is an optical artifact due to focus). From a preparation by Dr. E. A. Robson.

D. Electron micrograph through the surface of a cell of *Metridium*. The section passes obliquely through a cilium. A cilium, possibly the same one, can be seen in transverse section on the right of it.

E. The cilium and its section seen in D above under maximal enlargement to show the eleven fibres of which it is composed.

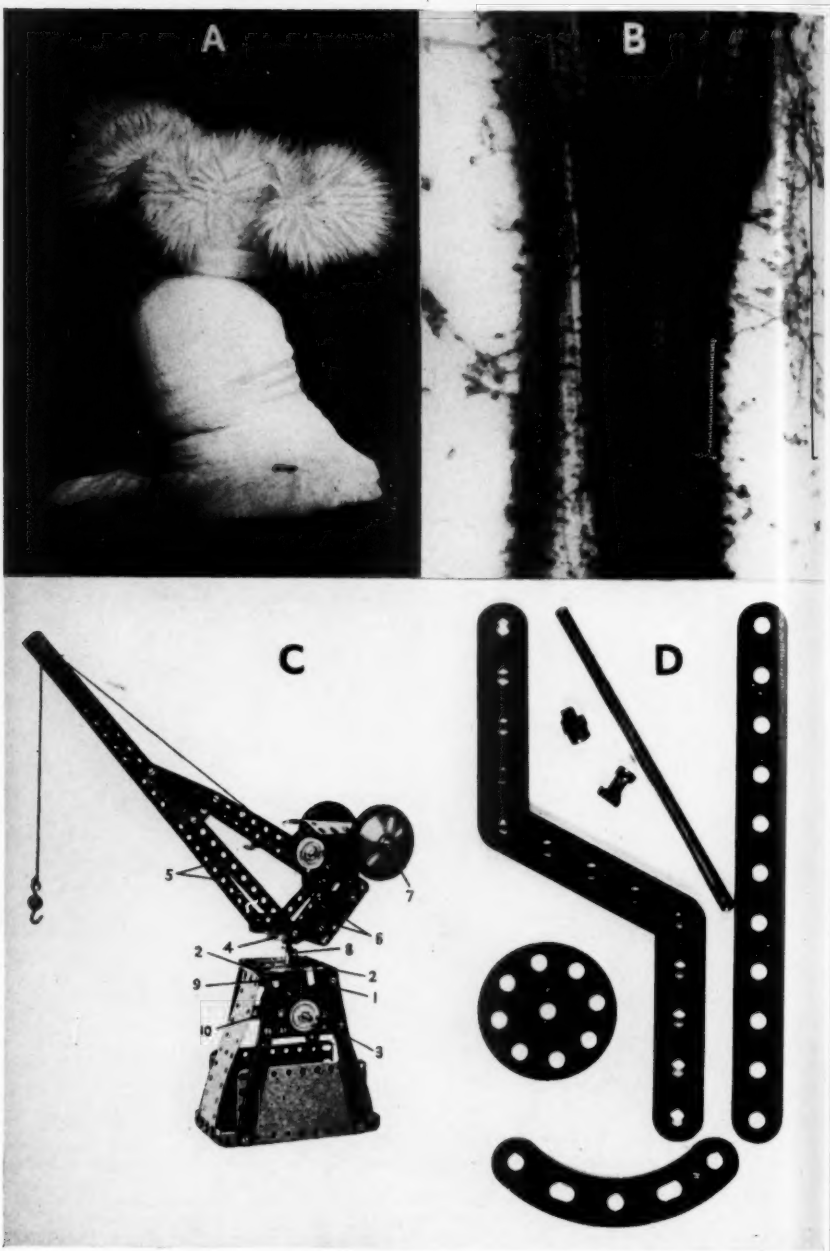

Fig. 4.—A. A sea-anemone (*Metridium*) in active movement (peristalsis).
B. Electron micrograph of the connective tissue of *Metridium canum*, to show the molecular banding of the fibres. Bar = 1/1,000 mm. Preparation by Dr. E. J. Batham.
C and D. A model crane and parts from a toy constructional set.

higher animals and plants this simple 9 : 2 fibrillar organisation is constant. The cilia of plants show it just as clearly as the cilia of the sea-anemone.

In analysing living structure we cannot go beyond the molecules of which it is composed. And the molecular organisation which the electron microscope enables us to see must in fact correspond to the working parts of the living machinery. By this knowledge several ingenious hypotheses have now been made to explain how muscles contract and how other vital activities take place—we are in fact getting near to the satisfaction of Kelvin's test; that we can make a model—at least in our mind's eye—of at least some of the living machinery.

ACKNOWLEDGEMENTS

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Fig. 4B from an electron micrograph by Dr. E. J. Batham.

Fig. 4C and D by courtesy of Meccano Ltd.

PROFESSOR W. WARDLAW, C.B.E.

ALL MEMBERS will have been grieved to learn of the death on December 19, 1958, of Professor William Wardlaw, C.B.E., D.Sc.

Professor Wardlaw first attended a meeting of the British Association in 1926 and, in the years which followed, developed an increasing interest in, and sympathy for, the views of the Association. He became a member of the Council of the Association in 1951 and a General Secretary in 1955—a position which enabled him to play an active and continuing part in the planning of the Association's new activities—until death intervened. In 1952, at Belfast, he was President of Section B (Chemistry), and his address on 'The Advancing Front of Chemistry' attracted a great deal of attention.

Professor Wardlaw was educated at Newcastle upon Tyne, first at Rutherford College, and then at Armstrong College, in the University of Durham. In 1918 he joined the staff of the Department of Chemistry, University of Birmingham. He proved to be an admirable university teacher and progressed to the rank of senior lecturer in inorganic chemistry. He was appointed to the chair of physical chemistry in the University of London, tenable at Birkbeck College, in 1937, and he held his professorship for twenty years until his retirement in 1957, when the title of Professor Emeritus was conferred on him.

For more than forty years Professor Wardlaw carried out valuable research in inorganic chemistry. In the 1930's his interest turned to the stereochemistry of metal complexes. This subject continued to hold his attention for the rest of his life, and by his work he made an important contribution in this field of study.

On taking up his appointment in London, he had barely succeeded in getting his new department organised when the Second World War began. At the conclusion of hostilities he was faced with two major tasks. He had to build up afresh a research group, and to plan and equip a new department. He attacked both tasks with characteristic vigour.

Professor Wardlaw held strongly the belief that university scientists should not lead an 'ivory tower' existence, and he seized every opportunity to broaden the impact of chemistry upon the community. He was extremely sympathetic towards the difficulties which faced science masters in schools through poor laboratory accommodation, and often spoke up strongly on this point. Scientific publication interested him enormously, and he gave considerable thought to the best ways of dealing with the ever-increasing volume of chemical papers. To the professional societies he gave generously of his time and found much pleasure in this service.

He was President of the Chemical Society for 1954–6 and was President of the Royal Institute of Chemistry at the time of his death. To be elected President of both the Chemical Society and the Royal Institute of Chemistry is an honour accorded to few, and is a measure of the esteem in which he was held by his professional colleagues and the confidence which his sound judgment inspired.

During the Second World War Professor Wardlaw was a joint secretary of the War Cabinet Scientific Advisory Committee, after which he became scientific adviser to the Committee of Appointments in the Ministry of Labour and National Service. Undoubtedly he had a flair for accurate judgment of character and ability, and his advice has been of great national benefit.

Scientists, and especially chemists, owe a great deal to Professor Wardlaw, and it is hard to realise that no longer will it be possible to call on his services or to seek his wise counsel.

USE OF CONTROLLED ENVIRONMENTS IN EXPERIMENTAL WORK[1]

by

PROF. J. P. HUDSON

THE central problem of the next generation will be to increase agricultural production more rapidly than the population is growing, so that the increasing numbers of people in the world can be fed better than at present. This will require great effort and considerable skill in increasing crop yields above the present levels, which are often far below the capacity of plants to yield. One of the main causes of low yields is the effect of adverse weather conditions, since it is rare for weather to be ideal throughout the life of any crop plant.

There are three ways of attacking this particular aspect of crop husbandry. The first, and in the long-run most important, is to breed varieties that are more tolerant of adverse weather and will yield better under natural conditions which are sub-optimal for the crops concerned. The second is to modify the weather around the plants, either by subtleties of cultural practices or by the much more expensive horticultural methods of using glasshouses and other forms of environmental control. The third and perhaps most exciting approach, though still in its infancy and unproven as a reliable aid to agriculture, is the possibility of altering the plant's responses to the weather by using chemical stimulants such as gibberellic acid. This remarkable material will break the dormancy of some plants and alter the growth habit of others, but no important practical applications have so far been worked out.

All these three approaches require an accurate knowledge of the plant environment and the effects of various environmental factors, such as light, temperature and moisture, on plant behaviour. It is difficult to obtain this information with sufficient precision out-of-doors since 'the weather' is so variable and unpredictable, but the introduction of new types of electric lamps has made it possible to grow plants satisfactorily under artificial light, thus offering the biologist the powerful new research weapon of 'environmental control'. This involves the provision of space in which plants can be grown under specified environmental conditions, usually with close control of temperature and light, and often with control of humidity and atmospheric composition. Various types of equipment are used including *growth cabinets*, big enough to accommodate the plants but not the operator; *temperature-controlled rooms* without light; *growth rooms* with sufficient light to enable green plants to make healthy growth comparable with that made out-of-doors; and *glasshouses* that offer the advantage of natural light but many disadvantages of control. The best-known installation, offering a wide range of conditions in growth rooms and glasshouses, was opened in 1949 by Dr. F. W. Went at the Earhart Plant Research Laboratory, at Pasadena in California, which came to be known as the 'phytotron', although that name did not figure in its official title (1). In the last few years other phytotrons have been built on the Continent, notably in Russia, France, Holland and Germany, and very large installations are now being planned in Australia, New Zealand and elsewhere. There is nothing comparable to these installations in Britain but about seventy university departments and research stations have equipment for the control of

[1] Paper delivered to Section M (Agriculture) on September 1, 1958, at the Glasgow Meeting of the British Association.

plant environment. Although most of these installations are on a very modest scale they are producing some useful and stimulating results (2), (3).

Uses of Controlled Environments

Controlled environments have proved to be useful in many fields of biological work particularly in physiology, ecology and the study of morphogenesis, and many fascinating experiments in these fields are described by Went (1), but the main interest in this paper is in agronomy, i.e. the study of the problems of crop production. Some of the main agronomical uses of controlled environments are summarised below, before considering one particular field of work in greater detail.

Production of uniform plant material

Biological material is inherently variable but experimental work is greatly facilitated if this variation can be reduced to a minimum, thus enabling smaller numbers of plants to be used in simpler experimental lay-outs. Closely controlled environments enable variations between plants to be reduced to the minimum.

Reproduction of seasonal conditions

Some types of plant behaviour occur in response to changes in seasonal weather. It may only be possible to study these aspects at one time of the year if plants are grown out-of-doors, when workers must wait patiently for the appropriate weather to cause seasonal changes. By using suitable controlled environments it is possible to reproduce any particular seasonal condition and so carry out experiments at any time of year, irrespective of season or weather.

Hastening development

Where it is required to take plants through successive generations as rapidly as possible, as in certain phases of plant breeding, it may not matter whether growth is 'normal' so long as the plant produces viable seed. Controlled environments are particularly useful in this sort of work, since plants can be brought prematurely to the flowering stage. For instance, plant breeders of the Cereal Crops Division, at Ottawa, are raising four or even five generations of wheat per annum in some of the breeding programmes and for the initial multiplication of seed stocks, representing a very considerable gain in the time which any particular programme takes. This can be of great importance where the breeder is literally engaged in a race as, for instance, between the rate at which he can produce new varieties of rust-resistant wheat and the rate at which the rust fungi can mutate.

Increasing growth rate

Where experimental work requires plants to make rapid growth, it is usually possible to provide conditions that will induce and sustain high growth rates once the requirements of the plant are known.

Retarding development and growth

Not only is it possible to hasten maturation by the use of controlled environments but the same methods may be used to slow down growth rates, or to keep plants in the vegetative condition and prevent them from maturing. This has value, for instance, in some types of genetical work with annuals and biennials.

Testing response of plants to 'weather'

An important part of the art of crop husbandry lies in choosing varieties most likely to yield well under particular, but largely unpredictable, weather conditions. It is essential that the chosen varieties should be able to *survive* the worst possible

weather that may be experienced, and *thrive* under the conditions that are most likely to occur. Trials out-of-doors may take several years to show whether a variety is suitable for a particular district, and many years before exceptional weather occurs to put the variety to the final test, but the initial screening of new varieties can be hastened by using controlled environments, to test their capacity to grow under certain conditions and to survive under others. This applies, for instance, to the resistance of perennial crop plants to 'test winters'; the ability of cereals to yield in cool summers with short days; and the adequacy of winter cold to break the dormancy of some perennial crop plants such as deciduous fruit trees. Controlled environments can also be used to study the responses of new varieties, by comparing them with established ones which are known to thrive in a particular district, thus helping in the planned production of new varieties 'tailored' for particular climatic conditions.

Study of effects of environmental factors

The ultimate aim of most research in agronomy is to show how plants can be induced to grow more rapidly, since *yield* is largely dependent on *growth*. Although the applications referred to above can be most valuable, fully justifying the use of controlled environments, the most important use of environmental control is probably in the study of environmental effects themselves to show how and why the development and growth of plants is affected by the weather. In the open, weather is so infinitely variable, unpredictable and complex, that it is most difficult to determine the precise effects of any one factor. Since the plant is affected simultaneously by a large number of factors, all of which are constantly varying at different, and largely independent rates, the use of controlled environments seems to offer the only reasonable hope of resolving the complexities of this situation, until techniques are available for assessing the high order interactions of all the complex factors that make up the natural weather in the field. The most promising approach is to use environments in which all factors are controlled and not more than one or two are varied at once, to produce manageable experimental data on the effects of the factors under study. An example of this type of work is shown by Miss Dullforce's studies of the interactions of three factors, namely temperature, photoperiod and light intensity, on the growth of lettuce plants, which were chosen as the experimental species for this pilot work because of their small size and suitability for growing in the restricted spaces of the available growth rooms (4). The information thus obtained should one day enable techniques to be worked out for studying or explaining the full effects of the weather in the field. This most important objective in agronomical work, although still remote, seems most likely to be achieved by the intelligent use of controlled environments. The final understanding of the responses of plants to the weather can only come from a study of the effects of environment at the biochemical level, a field still virtually unexplored.

Plants and the Weather

Although we are still far from an understanding of the effects of weather on plant behaviour, it is nevertheless stimulating to speculate on the effects of this type of knowledge on agricultural and horticultural practice. Work in controlled environments is showing how plants respond to certain isolated factors of the weather, and will no doubt one day reveal the whole story. It should then be possible to *predict* the plant's behaviour under any particular set of weather conditions. But, since weather rarely behaves according to expectation, it seems more likely that the knowledge will be used to explain, *in retrospect*, exactly why plants behaved as they did! A knowledge of environmental effects would, of course, show how plant responses could be changed by *altering the environment*, but there is little prospect

at present of the control of critical environmental factors such as light and temperature on a field scale except in some rather specialised cases in horticulture. The present position is therefore rather frustrating, since work in controlled environments seems likely to lead into a blind alley so far as any practical application is concerned, but there is another possibility. Although it may not be practicable to alter the behaviour of plants in the field by altering their environment, might it not be possible *to alter the plant's responses to the weather*? That would be a much more elegant approach, and one that might have significant applications in agricultural practice.

An investigation made in the University of Nottingham Department of Horticulture can be cited to illustrate this approach. Although the work has been done on the raspberry plant, which is not a crop of great agricultural significance, the principles might well be applied to other crop plants. The first stage is to study the behaviour of the plant in the field, to distinguish clearly between the various phases of development which occur in response to seasonal changes in the weather. It is here that the raspberry plant is of outstanding interest since each shoot passes through a series of distinct phases in its two-year life. First is the phase of *initiation*, when a bud is laid down on a root; then a phase of *elongation*, when the shoot grows to the surface, followed by a phase of *modified vegetative growth*, when a rosette of leaves is formed; this is followed by a phase of *dormancy*, when further development of the vegetative shoot virtually ceases, at ground level. In the following spring a period of *strong vegetative growth* ensues, during which the shoot elongates to several feet. This phase ceases in late summer or early autumn, when the tip rosettes again and *flowers are initiated* in the axillary buds, although the buds are still incapable of normal opening. *Dormancy is broken* by cold during the winter time, so that the next phase, *flowering*, can be induced by warmer weather in the early summer, after which the shoots *fruit* and then *die*.

Dr. I. H. Williams has shown that these successive phases are, in fact, dependent on seasonal changes in the weather (5, and in press). In a series of elegant experiments Williams has shown how the behaviour of raspberry shoots is affected by different weather factors, and has also shown that the normal two-year cycle can be telescoped to six months or extended over a period of years by subjecting plants to appropriate conditions.

Once these responses have been worked out, the next step is to place plants in a particular environment where their responses can be precisely forecast, and then subject them to various chemical treatments to see whether the 'normal' responses can be modified. This has proved to be quite possible. For instance, plants can be induced to continue to grow in an environment where they would normally cease to do so, or stimulated to elongate from the rosetted 'semi-dormant' condition, by treatment with gibberellic acid, and there seem to be other similar possibilities, which are now being investigated.

The interest in this new approach lies in the possibilities of controlling the responses of plants to marginal weather conditions. If it was known that certain observable weather conditions would cause a check to plant growth it might be worth-while to induce development to continue under those conditions by the judicious use of a chemical stimulant, thus preventing the growth of a crop plant from being checked by sub-optimal conditions. In that way the crop might be brought to maturity earlier, or persuaded to grow for longer and thus produce a heavier yield.

This is only one example of the ways in which yields might be increased, by the application of knowledge that can most easily be obtained through the use of controlled environments for experimental work. We are witnessing the start of a new field of scientific endeavour, with unlimited potentialities in crop husbandry, and one which holds great promise of solving some of the outstanding problems of

agriculture and horticulture. It seems likely that a better understanding of the relationship between plants and the weather will show how yields can be increased in the field, thus helping in the struggle to match world resources with world demands for food and other products of agriculture.

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THE DIRECTORY OF NATURAL HISTORY AND FIELD STUDY SOCIETIES

THE Council of the British Association for the Advancement of Scien have, at the invitation and with the financial backing of the Carneg United Kingdom Trust, prepared a new edition of *The Directory Natural History Societies* which was first published in 1948 by t Amateur Entomologists Society.

The Directory, which was published at the beginning of March, 195 covers archaeological, astronomical, biological, botanical, geographic geological, meteorological and zoological societies, both national a local amateur bodies—and other cognate societies. The informati given for each society is listed under the following headings: ti and address, name and address of Secretaries, aims and objec conditions of membership, amenities, meetings, publications a affiliations. Societies are arranged alphabetically under the main hea ings of natural history, archaeology, archaeology and natural histor societies with general interests, geology, astronomy, and meteorolog The arrangement of the societies within the sections is strictly alph betical according to the titles supplied by the Secretaries. There is final geographical reference section in which the names of the societi are listed alphabetically according to counties. This geographical secti has been compiled so that naturalists moving from one district another may be able to get into touch with others having simil interests.

The Council of the Association hopes that the publication of t *Directory* which contains information about some 800 societies w stimulate field studies throughout the country and, by increasing t possibility of co-operation between professional and amateur scientis will make a real contribution towards our understanding and appreci tion of the world in which we live.

Copies of the *Directory* may be ordered (20*s*., plus packing and posta 1*s*. 6*d*.) from The Secretary, British Association for the Advanceme of Science, 18 Adam Street, Adelphi, W.C.2. A limited edition interleaved copies is available at £1 5*s*., plus packing and posta 1*s*. 6*d*.